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Assistant Commissioner for Patents  
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Washington, D.C. 20231

Re: HIGH BRIGHTNESS TRANSFLECTIVE LCD AND METHOD USING  
TUNABLE MIRROR  
Docket No. 99SC132US2

Sir:

Transmitted herewith for filing under 35 U.S.C. 111 and 37 CFR 1.53 is the patent application of BRUCE K. WINKER and WILLIAM J. GUNNING entitled HIGH BRIGHTNESS TRANSFLECTIVE LCD AND METHOD USING TUNABLE MIRROR.

Enclosed are:

- 51 pages of written description, claims and abstract.
- 18 sheets of informal drawings.
- An Assignment of the invention to Rockwell Technologies, LLC.
- Executed Declaration and Power of Attorney.

The filing and recording fees have been calculated as shown below:

Basic Fee		\$690.00
Total Claims	(69 - 20) x \$18.00 =	882.00
Independent Claims	(11 - 3 ) x \$78.00 =	624.00
Assignment Recording Fee		40.00
Total Fee:		\$ 2,236.00

Please charge Deposit Account No. 18-1750 in the amount of \$ 2,236 to cover the filing and recording fees. We authorize the Commissioner to charge (1) payment of any additional filing fees required under 37 CFR §1.16, (2) payment of any patent application processing fees under 37 CFR §1.17 associated with this communication, or (3) payment of any fees that occur during the pendency of this application (and to credit any overpayment) to Deposit Account No. 18-1750. We enclose a duplicate copy of this sheet.

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Figure 1 consists of 12 subplots, labeled (a) through (l), arranged in a 6x2 grid. Each subplot shows a time course of a specific physiological parameter over a 10-minute period. The x-axis for all plots represents time in minutes, from 0 to 10. The y-axis represents the value of the parameter. Each plot includes a horizontal line for the baseline value and a series of data points with vertical error bars representing the standard error. The parameters shown are: (a) HR (b/min), (b) SV (L/min), (c) CO (L/min), (d) MAP (mmHg), (e) PVR (mmHg), (f) SVR (mmHg), (g) PPA (mmHg), (h) PVP (mmHg), (i) PVP/PPA, (j) PVP/PPA, (k) PVP/PPA, and (l) PVP/PPA. The plots show various responses to a stimulus, with some parameters increasing and others decreasing over time.

OF

FOR

ON

Docket No. 99SC132US2

Rockwell Technologies, LLC

## HIGH BRIGHTNESS TRANSFLECTIVE LCD AND METHOD USING TUNABLE MIRROR

### BACKGROUND OF THE INVENTION

#### Field of the Invention

5           This invention is concerned with liquid crystal displays (LCDs) and particularly with transflective LCDs that achieve lower battery usage and higher contrast.

#### Description of the Related Art

10           Conventional transflective LCDs have a partially-reflective partially-transmissive mirror element (also known as a transflector) which reflects ambient light received from the viewing screen back through the LCD, and transmits backlight emission which is switched on  
15 when ambient lighting is low.

          In conventional transflective LCDs, the utilization of light is inefficient because light is both reflected and transmitted at the same time, by the partially-reflective partially-transmissive mirror. Additionally,  
20 the transmission and reflection have fixed values. Since at any given time, the sum of the transmission and reflection of a mirror can not exceed 100%, the partially-reflective partially-transmissive mirror sacrifices efficiency by simultaneously operating as a

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reflector and a transmitter. Typically such mirrors have a 70-90% reflectance and a 10-30% transmission.

To compensate for such inefficiency, more battery power must be used to increase the backlight emission  
5 when operating in the transmissive mode in low ambient light. Likewise, contrast is lost when operating in the reflective mode, at high ambient light.

10 SUMMARY OF THE INVENTION

This invention provides a system and method which improve the efficiency of conventional transflective LCDs by replacing the partially-reflective partially-transmissive mirror with a tunable mirror. A tunable mirror is any  
15 device having controllable degrees of transmission and reflection.

The advantage of using a tunable mirror is that it can be switched between "reflective" and "transmissive" modes to primarily reflect light when ambient lighting is  
20 high, and to primarily transmit light when ambient lighting is low and backlighting is needed. This saves battery life by reducing the amount of backlighting needed when operating the LCD in the transmissive mode, and increases contrast and brightness when operating in  
25 the reflective mode.

The electrochemical reversible mirror (REM) is a suitable type of tunable mirror for use with this invention. Additionally, tunable mirrors may be constructed from a plurality of optical elements, at  
30 least one of which has an electrically switchable optical property.

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One suitable construction for the tunable mirror includes a cholesteric liquid crystal reflector with a quarter-wave ( $\lambda/4$ ) retarder. In this combination, the liquid crystal reflector is switchable between reflecting and transmitting states of operation to give the mirror its tunable characteristic.

Another suitable construction for the tunable mirror includes a reflective polarizer with a zero to half-wave ( $0-\lambda/2$ ) tunable liquid crystal retarder. Such retarder is and is switchable between  $\lambda/2$  and  $0\lambda$  states of operation to give the mirror its tunable characteristic.

A third suitable construction for the tunable mirror includes a cholesteric reflector with a negative quarter-wave to positive quarter-wave ( $\pm\lambda/4$ ) tunable liquid crystal retarder. Such retarder is switchable between  $+\lambda/4$  and  $-\lambda/4$  states of operation to give the mirror its tunable characteristic.

There are various possibilities for controlling the mirror and backlight. For example, mirror and backlight control systems may be employed which operate the mirror and backlight in tandem, such that when the backlight is switched on, the mirror is set to the transmissive state. Another possibility is to set the mirror and backlight controls automatically responsive to the level of ambient light.

#### BRIEF DESCRIPTION OF THE DRAWINGS

**FIG. 1** is a schematic diagram of an LCD in accordance with the present invention LCD operating in the reflective mode.

FIG. 2 is a schematic diagram of the LCD of FIG. 1, operating in the transmissive mode.

FIG. 3 is a schematic diagram of a tunable mirror comprising a liquid crystal reflector and quarter waver retarder, operating in the reflective mode.

FIG. 4 is a schematic diagram of the tunable mirror of FIG. 3 operating in the transmissive mode.

FIG. 5 is a schematic diagram of an LCD with the tunable mirror of FIG. 3 operating in the reflective mode.

FIG. 6 is a schematic diagram of the LCD of FIG. 5 operating in the transmissive mode.

FIG. 7 is a schematic diagram of a tunable mirror comprising a reflective polarizer with a zero to half-wave ( $0-\lambda/2$ ) tunable liquid crystal retarder, operating in the reflective mode.

FIG. 8 is a schematic diagram of the tunable mirror of FIG. 7, operating in the transmissive mode.

FIG. 9 is a schematic diagram of an LCD with the tunable mirror of FIG. 7, operating in the reflective mode.

FIG. 10 is a schematic diagram of the LCD of FIG. 9, operating in the transmissive mode.

FIG. 11 is a schematic diagram of an alternate construction for an LCD with the tunable mirror of FIG. 7, which includes a  $\lambda/4$  retarder.

FIG. 12 is a schematic diagram of an alternate construction for the LCD with the tunable mirror of FIG. 8.

FIG. 13 is a schematic diagram of a tunable mirror comprising a cholesteric reflector with a negative

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quarter-wave to positive quarter-wave ( $\pm\lambda/4$ ) tunable liquid crystal retarder, operating in the reflective mode.

FIG. 14 is a schematic diagram of the tunable mirror of FIG. 13, operating in the transmissive mode.

FIG. 15 is a schematic diagram of an LCD with the tunable mirror of FIG. 13, operating in the reflective mode.

FIG. 16 is a schematic diagram of the LCD of FIG. 15, operating in the transmissive mode.

FIG. 17 is a schematic diagram of an alternate construction for the LCD with the tunable mirror of FIG. 13.

FIGS. 18a - 18c are perspective views illustrating the appearance of electronic apparatus of the present invention, in which FIG. 18a is a cellular telephone, FIG. 18b is a watch, and FIG. 18c is a laptop computer.

## DETAILED DESCRIPTION OF THE INVENTION

The present invention replaces the partially-reflective partially-transmissive mirror used in prior art transflective LCDs with a tunable mirror. There are many ways to make transflective LCDs. While a particular type of LCD is shown in these figures, the invention is applicable in general to any transflective LCD in which the partially-reflective partially-transmissive mirror can be replaced by a tunable mirror.

FIGS. 1 and 2 are diagrams illustrating an LCD 100, according to the present invention, operating in the reflective and transmissive mode, respectively.

The LCD 100 includes a liquid crystal cell 102; a tunable mirror 104 behind the cell; a backlight 106 which is located behind the tunable mirror 104; a first polarizer 108 in front of the cell 102; a second polarizer 110 between the cell 102 and the tunable mirror 104; a control 118 for the tunable mirror 104; and a control 120 for the backlight 106.

The liquid crystal cell 102 may be a Supertwisted-Nematic (STN) cell, an Active Matrix Twisted-Nematic (TN) cell or a Passive TN cell. The construction of the liquid crystal cell typically includes a liquid crystal layer sandwiched between a pair of segmented electrodes.

In a normally white mode of operation, the cell 102 can be either in an ON (light emitting) state or an OFF state, wherein voltage is applied across the electrodes of the cell in the OFF state and no voltage is applied across the cell in the ON state. The first and second polarizers 108 and 110 are oriented such that when the cell is in the ON state, light entering through one polarizer is rotated upon transmission through the cell, such that the polarization direction is approximately parallel to the transmission axis of the other polarizer, and exits through that polarizer. When the cell is in the OFF state, light entering through one polarizer is rotated by the cell, such that the polarization direction is approximately orthogonal to the transmission axis of the other polarizer, and is therefore blocked or absorbed by that polarizer. In the example of a 90° TN cell



operating in the normally white mode where the cell rotates light by  $90^\circ$  in the ON state, the polarizers have mutually orthogonal planes of polarization.

In an STN cell the planes of polarization may not be  
5 orthogonal. A normally black mode may also be used, in  
which the voltage is applied in the ON state and no  
voltage in the OFF state. In the example of a 90° TN cell  
operating in the normally black mode the polarizers are  
parallel (For a reference on STN cells see T.J. Scheffer  
10 and J. Nehring, "Supertwisted Nematic LCDs," Society for  
Information Display Seminar Lecture Notes, Vol. 1, M-12,  
May 15, 2000, and the references therein.)

The tunable mirror 104 can be switched between reflective and transmissive modes, for primarily reflecting or primarily transmitting light, respectively. More detailed examples of tunable mirrors will be described below.

The backlight 106 can be switched between emissive and non-emissive states of operation, for emitting light in its emissive state when ambient light entering the liquid crystal cell from the opposite side is too low, and is therefore below a "viewability threshold". Some examples of a suitable backlight assembly can be found in Okumara, (U.S. Pat. No. 6,008,871). Additionally, manufacturers of suitable backlights for transflective displays are Durel Corporation and Eltech.

While the liquid crystal cell 102, tunable mirror 104, polarizers 108 and 110 are illustrated as being separated, this is for convenience of illustration; in practice these elements would normally be bonded together with adhesives having compensatory indices of refraction.

The construction of these individual elements is well known in the LCD art. For example, see Okumara, (U.S. Pat. No. 6,008,871); and transflective LCD units having these components (with a partially-reflective partially-transmissive mirror) are sold by companies such as Seiko-Epson and Optrex.

Besides those illustrated, other optional elements are left out of the illustrations because they are not necessary to describe the present invention. These include compensation (retardation) films, which can be located on each side of the liquid crystal cell 102, and are used with an STN cell. Such elements are well known.

Additionally, a light diffusing element may be added to produce a diffused image. Such light diffusing element can be made of embossed plastic plate, or a plastic plate dispersed with beads. In addition, diffusing beads can be mixed into one of the adhesive layers adjacent to any of the above-described elements (See Okumura). Also, it may be possible to produce a tunable mirror with a matte surface for obtaining a diffused surface, and some mirrors may have an inherent light diffusion quality so an additional light diffusing element is not required for diffusion, as will be mentioned in more detail in the discussion regarding tunable mirrors.

Moreover, in conventional transflective LCDs, the backlight is switched to the emissive state when operating in a transmissive mode. In the present invention, both the backlight and tunable mirror need to be controlled. There are several options for this. The mirror and backlight controls 118 and 120 can be either

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manually set by the user or automatically responsive to the level of ambient light. The user may also be given the option of setting the controls at either manual or automatic ambient light responsive modes. In a system  
 5 which is automatically responsive to ambient light, an ambient light sensor can be used to switch the backlight to its emissive state and set the mirror in its transmissive mode at low ambient light, and at high ambient light, switch the backlight to its non-emissive  
 10 state and set the mirror in its reflective mode, for example. Additionally, the two controls **118** and **120** may either operate independently of each other, or in tandem. Where both controls are operated by applying a source of electrical potential, two control circuits operating in  
 15 series or parallel may be utilized.

Fig. 1 illustrates the operation of the LCD **100** in the reflective mode in which there is high ambient light, and the tunable mirror **104** is switched to operate in the reflective mode, indicated by the shading **128**.  
 20 Additionally, the backlight **106** is switched to the non-emissive state of operation **129**. For the purpose of illustration, the liquid crystal cell **102** is assumed to be a  $90^\circ$  TN cell operating in a normally white mode, and in its ON state, wherein it rotates the plane of  
 25 polarization of linearly polarized light by  $90^\circ$ . Additionally, for the purpose of illustration, polarizers **108**, **110** have mutually orthogonal planes of polarization in the vertical and horizontal directions, respectively. Although this assumption may not be true for all  
 30 displays, as in the case of an STN cell, or a normally black mode display, it is adopted for the purpose of

simplifying the illustration and does not limit the invention to TN cells or white mode displays.

First, randomly polarized ambient light **126**, indicated by unpolarized light vectors **130**, travels  
5 through the first polarizer **108**, where it is linearly polarized, as indicated by the polarized light vector **132**. The light then travels through the liquid crystal cell **102**, where it is rotated to have a plane of polarization approximately parallel to the transmission  
10 axis of the second polarizer, indicated by the dot **134** representing a light vector coming out of the plane of the paper. The light then passes through the second polarizer **110**, maintaining its linear polarization **136**, and is primarily reflected by the tunable mirror **128**. The  
15 reflected light then follows a reversed path with successive polarizations **138**, **140**, **142** and **144**, to emerge as an LCD output **145**. (When the cell **102** is in the OFF state, the light entering through the first polarizer **108** travels through the cell **102**, where it is rotated to have  
20 a plane of polarization approximately orthogonal to the transmission axis of the second polarizer and is blocked.)

FIG. 2 illustrates the operation of the LCD **100** in the transmissive mode, in which the tunable mirror **104** is  
25 switched to operate in the transmissive mode, indicated by the absence of shading **200**. Additionally, the backlight **106** is switched to the emissive state of operation **204**. As in the description of FIG. 1, the liquid crystal cell **102** is again assumed to rotate the  
30 plane of polarization of linearly polarized light by  $90^\circ$ . First, randomly polarized backlight emission **202**,

indicated by unpolarized light vectors 206, is primarily transmitted through the tunable mirror 104. The resultant unpolarized light, indicated by vector 208, then travels through the second polarizer 110 and is linearly polarized 210. Its polarization is then rotated by the liquid crystal cell 102 to a linear polarization 212, approximately parallel to the transmitting axis of the first polarizer 108. Finally the light exits the first polarizer 108 with linear polarization 214, to emerge as the LCD output 216. (When the liquid crystal cell 102 is in the OFF state, the light exiting the cell 102 has a polarization direction orthogonal to the transmitting axis of the first polarizer 108 and is blocked.)

#### TUNABLE MIRRORS

For purposes of this invention, a tunable mirror is defined as any device having a controllable transmission and reflection. This includes a transmission/reflection which can be switched among either discrete or continuous states. An electro-optic device is one whose optical properties change with an electric signal. This invention contemplates the use of any electro-optic or other device which acts as a tunable mirror for a transflective LCD.

Tench (U.S. Pat. No. 5,923,456) discloses a suitable reversible electrochemical mirror (REM) having controllable reflective and transmissive modes. The REM can be controlled by applying a source of electrical potential which has reversible polarity and adjustable potential. The REM takes about 1 second to switch between reflective and transmissive modes. Additionally,

the REM may have a matte surface to produce a diffused reflectance. The REM can achieve a transmittance of up to 60% due to light absorption, and therefore has limited efficiency.

5        Additionally, tunable mirrors may be constructed by combining a plurality of optical elements, at least one of which is an electro-optic device having switchable optical properties. FIGS. 3-17 illustrate examples of such tunable mirrors, and LCDs incorporating these  
10        mirrors, according to this invention.

FIGS. 3-6 illustrate a first tunable mirror assembly 300, and an LCD 500 incorporating the tunable mirror 300. The tunable mirror 300 includes a switchable cholesteric liquid crystal reflector 302 with a quarter-wave ( $\lambda/4$ )  
15        retarder 304 and a control 305 for the liquid crystal reflector 302. The liquid crystal reflector 302 is controllably switchable between reflecting and transmitting states of operation, for reflecting circularly polarized light of a particular rotational  
20        direction in the reflecting state, and for transmitting light in the transmitting state. Such Cholesteric liquid crystal devices are commercially available from Kent Displays and Advanced Display Systems (ADS). Preferably, the cholesteric liquid crystal reflector 302 should be  
25        custom designed to have a single addressing pixel, which has the same dimensions as the overall LCD. Such liquid crystal reflector has a diffuse reflectance in the reflecting state and thus will produce a diffused image without the addition of a light diffusing element. When a  
30        voltage (approximately between 20 and 80 Volts) is applied to the reflector 302 (i.e. in the transmitting

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state) it changes from a homeotropic state, in which light is transmitted without a change in polarization. (For a reference see D.K. Yang, J.L. West, L.C. Chien, and J.W. Doane, "control of Reflectivity and Bistability in Displays using Cholesteric Liquid Crystals," J. Appl. Phys. 76, 1331 (1994)).

The  $\lambda/4$  retarder **304** is an element used for conversion of light between circular and linear polarization forms. It converts horizontal or vertical linearly polarized light to right-handed or left-handed circularly polarized light, depending on the orientation. Conversely, it will convert right-handed or left-handed circularly polarized light to linearly polarized light, and is substantially transmissive to randomly polarized light. Such  $\lambda/4$  retarder can be either birefringent crystal or oriented polymer film and are manufactured by Fuji Film, Nitto Denko, and Meadowlark Optics. (For a reference see Polarization Manipulation with Retarders, Meadowlark Optics, Product Catalogue, 1999-2000).

Furthermore, the liquid crystal reflector **302** and  $\lambda/4$  retarder **304** are oriented with respect to each other such that in the reflective mode, the reflector **302** reflects light received from the retarder **304**. Also, in FIGS. 3 - 6, the liquid crystal reflector **302** and  $\lambda/4$  retarder **304** are illustrated as being separated, however, as components of an LCD, these elements would normally be bonded together.

FIG. 3 illustrates the operation of the tunable mirror **300** in the reflective mode in which the liquid crystal reflector **302** is in the reflecting state. In this state, the liquid crystal reflector **302** is capable of

reflecting circularly polarized light of one particular rotational direction, e.g. right handed circular polarization but not left handed, indicated by the circular reflection vector **306**.

5 First, linearly polarized light **308** (e.g. in the horizontal direction), as indicated by the polarized light vector **312**, is converted by the  $\lambda/4$  retarder **304** to a circular right handed polarization, indicated by the polarized light vector **314**. The light is then reflected  
10 by the liquid crystal reflector **302**, maintaining its circular right handed polarization **316**, and travels back through the  $\lambda/4$  retarder **304** which converts it back to a horizontal linear polarization **318**.

FIG. 4 illustrates the operation of the tunable  
15 mirror **300** in the transmissive mode, in which the liquid crystal reflector **302** is in the transmitting state. In this state the liquid crystal reflector is transmits light, as indicated by the absence of a reflection vector **400**. Randomly polarized light **402**, indicated by the  
20 unpolarized light vectors **404**, is transmitted through both the liquid crystal reflector **302** and  $\lambda/4$  retarder **304**, maintaining its random polarization indicated by vectors **406** and **408**.

FIGS. 5 and 6 illustrate the operation of the LCD  
25 **500** which incorporates the tunable mirror **300**. The elements of the LCD **500** are essentially the same as those in the previous figures, with the exception of the tunable mirror, and tunable mirror control. These elements are a liquid crystal cell **502** located in front  
30 of the  $\lambda/4$  retarder **304** of the tunable mirror **300**; a backlight **506** which is located behind the liquid crystal

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reflector 302 of tunable mirror 300 and can be switched between emissive and non-emissive states; a first polarizer 508 in front of the cell 502; a second polarizer 510 between the cell 502 and the  $\lambda/4$  retarder 304; and a control 520 for the backlight 506. Again, for the purpose of illustration, the liquid crystal cell 502 is assumed to be a  $90^\circ$  TN cell operating in the normally white mode, and in its ON state wherein it rotates the plane of polarization of linearly polarized light by  $90^\circ$ . Also for the purpose of illustration, the first and second polarizers 508 and 510 have mutually orthogonal planes of polarization in the vertical and horizontal directions, respectively.

FIG. 5 illustrates the LCD 500 operating in the reflective mode, in which the liquid crystal reflector 302 is in the reflecting state, as indicated by the circular reflection vector 306, and the backlight 506 is in the non-emissive state 526. First, randomly polarized ambient light 526, indicated by unpolarized light vectors 530, travels through the first polarizer 508, where it is linearly polarized, as indicated by the polarized light vector 532. The light then travels through the liquid crystal cell 502, where its is rotated to have a plane of polarization approximately parallel to the transmission axis of the second polarizer, as indicated by the polarized light vector 534 and through the second polarizer 510, maintaining its linear polarization 536. The light then passes through the  $\lambda/4$  retarder 304 wherein it is circularly polarized in the right handed direction 538. The circularly polarized light 538 is then reflected by liquid crystal reflector 302, following a

reversed path with successive polarizations 540, 542, 544, 546, and 548 to emerge as an LCD output 550. (When the liquid crystal cell 502 is in the OFF state, the light entering through the first polarizer 508 travels through the cell 502, where it is rotated to have a plane of polarization approximately orthogonal to the transmission axis of the second polarizer 510 and is blocked.)

FIG. 6 illustrates the LCD 500 operating in the transmissive mode, in which the liquid crystal reflector is in the transmitting state, as indicated by the absence of a reflection vector 400, and the backlight is in its emissive state 600. First, randomly polarized backlight 602, indicated by unpolarized light vectors 606, is transmitted through the liquid crystal reflector 302 and  $\lambda/4$  retarder 304, having unpolarized light vectors 607 and 608. The resultant light then travels through the second polarizer 510 and is linearly polarized 610. Its polarization is then rotated by the liquid crystal cell 502 to an approximately linear polarization 612, parallel to the transmitting axis of the first polarizer 508. Finally the light passes through the first polarizer 508 with linear polarization 614, to emerge as the LCD output 616. (When the liquid crystal cell 502 is in the OFF state, the light exiting the cell 502 has a polarization direction orthogonal to the transmitting axis of the first polarizer 508 and is blocked.)

FIGS. 7-12 illustrate a second tunable mirror assembly 700, and LCDs 900, 1100 and 1200 incorporating the tunable mirror 700. The tunable mirror 700 includes a reflective polarizer 702, a tunable liquid crystal zero

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to half-wave ( $0-\lambda/2$ ) retarder 704, and a control 705 for the  $0-\lambda/2$  retarder 704. The reflective polarizer 702 reflects linearly polarized light of one direction, (e.g. the horizontal direction) and transmits linearly polarized light of another direction (e.g. the vertical direction). Commercially available reflective polarizers (supplied through Merck and 3M) have a specular rather than a diffuse reflectance.

The  $0-\lambda/2$  retarder 704 is controllably switchable between  $0\lambda$  and  $\lambda/2$  states of operation, for rotating the plane of polarization of linearly polarized light by  $90^\circ$  in the  $\lambda/2$  state, and for transmitting light with no change in the  $0\lambda$  state. (see Meadowlark Optics) Such retarder is typically of a nematic type, and is switchable to the  $0\lambda$  state with the application of a voltage (approximately 10V) at a speed of 20 ms, and works in analogue mode.

Furthermore, the reflective polarizer 702 and retarder 704 are oriented with respect to each other such that in the reflective mode, the reflective polarizer 702 reflects light received from the retarder 704, as illustrated in FIGS 7-12. Also, in FIGS. 7-12, the reflective polarizer 702 and retarder 704 are illustrated as being separated, however, as components of an LCD, these elements would normally be bonded together. Additionally, in an LCD where a diffuse reflectance is desired, an additional light diffusing element may be added with this type of tunable mirror. In this case it is preferable to use a holographic diffuser that does not scramble the polarization.

FIG. 7 illustrates the operation of the tunable mirror 700 in the reflective mode, in which the  $0-\lambda/2$  retarder 704 is in the  $0\lambda$  state 708. In the simplest case, light having horizontal linear polarization 710 as indicated by the polarized light vector 712, is transmitted through the retarder 704 and reflected by the reflective polarizer 702, back through the retarder 704, having successive polarizations 714, 716, and 718. It is also possible for the light entering to have both vertical and linear polarization components. In this case, still only the component having horizontal linear polarization will be reflected back.

FIG. 8 illustrates the operation of the tunable mirror 700 in the transmissive mode in which the retarder 704 is in the  $\lambda/2$  state 800. First, randomly polarized light 802, as indicated by the unpolarized light vectors 804 is transmitted through the reflective polarizer 702, wherein only the vertical component is transmitted, as indicated by the polarized light vector 806. Thereafter, the light passes through the retarder, wherein its polarization is rotated  $90^\circ$ , as indicated by polarized light vector 808.

FIGS. 9 and 10 illustrate the operation of the LCD 900 which incorporates the tunable mirror 700. The elements of the LCD 900 are essentially the same as those in the previous figures, with the exception of the tunable mirror, and tunable mirror control. These elements are a liquid crystal cell 902 located in front of the  $0-\lambda/2$  retarder 704 of the tunable mirror 700; a backlight 906 which is located behind the reflective polarizer 702 of tunable mirror 700 and can be switched

between emissive and non-emissive states of operation; a first polarizer 908 in front of the cell 902; a second polarizer 910 between the cell 902 and the retarder 704; and a control 920 for the backlight 906. Again, the liquid crystal cell 902 is assumed to be a  $90^\circ$  TN cell operating in a normally white mode, and in its ON state, wherein it rotates the plane of polarization of linearly polarized light by  $90^\circ$ . Also for the purpose of illustration, the first and second polarizers 908 and 910 have mutually orthogonal planes of polarization in the vertical and horizontal directions, respectively.

FIG. 9 illustrates the LCD 900 operating in the reflective mode, in which the retarder 704 is in the  $0\lambda$  state 708, and the backlight 906 is in its non-emissive state 926. First, randomly polarized ambient light 928, indicated by unpolarized light vectors 930, travels through the first polarizer 908, where it is linearly polarized, as indicated by the polarized light vector 932. The light then travels through the liquid crystal cell 902, where it is rotated to have a plane of polarization approximately parallel to the transmission axis of the second polarizer 910, as indicated by the polarized light vector 934, and passes through the second polarizer 910, maintaining its linear polarization 936. The light is then transmitted through the  $0-\lambda/2$  retarder 704 maintaining its linear polarization 938, and is reflected back by the reflective polarizer 702. The light then follows a reversed path with successive polarizations 940, 942, 944, 946, and 948 to emerge as an LCD output 950. (When the liquid crystal cell 902 is in its OFF state, the light entering through the first

polarizer 908 travels through the cell 902, where it is rotated to have a plane of polarization approximately orthogonal to the transmission axis of the second polarizer 910, and is blocked.)

5        FIG. 10 illustrates the LCD 900 operating in the transmissive mode, in which the  $0-\lambda/2$  retarder 704 is in the  $\lambda/2$  state 800, and the backlight 906 is in the emissive state 1000. First, randomly polarized backlight emission 1002, indicated by unpolarized light vectors

10    1004, is transmitted through the reflective polarizer 702, wherein only the vertical component is transmitted, as indicated by the polarized light vector 1006.

Thereafter, the light passes through the retarder 704 wherein its polarization is rotated  $90^\circ$ , as indicated by

15    polarized light vector 1008. The light then passes through the second polarizer 910 maintaining its linear polarization 1010. Its polarization is then rotated by the liquid crystal cell 902 to an approximately linear polarization 1012, parallel to the transmitting axis of

20    the first polarizer 908. Finally the light passes through the first polarizer 908 with linear polarization 1014, to emerge as the LCD output 1016. (When the liquid crystal cell 902 is in its OFF state, the light exiting the cell 902 has a polarization direction orthogonal to

25    the transmitting axis of the first polarizer 908 and is blocked).

FIG. 11 illustrates an LCD 1100, similar to the LCD 900 in which a  $\lambda/4$  retarder 1102 is located between the backlight 906 and reflective polarizer 702. As is known

30    in the art the placement of a  $\lambda/4$  retarder 1120 between a backlight 906 and a reflective polarizer 702 can improve

006260" 82792960

the brightness of the display. This is because horizontally polarized light not transmitted by the reflective polarizer 702 in the transmissive mode is reflected back through the  $\lambda/4$  retarder 1120. The light is then circularly polarized in the right handed rotational direction, and is reflected back through the retarder as left handed circularly polarized light. The light then emerges through the retarder 1120 with vertical linear polarization, and passes through the reflective polarizer 702. (See Taber, U.S. Pat. No. 5,731,886).

It is also possible to assemble the LCD 900 without the second polarizer 910. This is because the reflective polarizer 702 performs the function of the second polarizer 910 by filtering out the light not rotated by the liquid crystal cell. FIG. 12 illustrates this LCD assembly 1200.

FIGS. 13-17 illustrate a third tunable mirror assembly 1300, and LCDs 1500 and 1700 incorporating the tunable mirror 1300. The tunable mirror 1300 includes a cholesteric reflector 1302, a negative quarter-wave to positive quarter-wave ( $\pm\lambda/4$ ) liquid crystal retarder 1304, and a control 1306 for the  $\pm\lambda/4$  retarder.

The cholesteric reflector 1302 reflects circularly polarized light having a polarization of one rotational direction, and transmits circularly polarized light of the opposite rotational direction. The cholesteric reflector 1302 may be a diffuse reflecting cholesteric liquid crystal polymer film, which diffuses light. Such reflector may be made according to the process described in Wacker-Chemie, R. Maurer, F.H. Kreuzer, and J.

Stohrer, "Cholesteric Reflectors with a Color Pattern",  
SID 94 Digest, p. 399 (1994).

006260" SET 9/960  
The  $\pm\lambda/4$  retarder functions similarly to the  $\lambda/4$   
retarder in that it converts light between circular and  
5 linear polarization forms. However, the  $\pm\lambda/4$  retarder  
**1304** is controllably switchable between  $-\lambda/4$  and  $+\lambda/4$   
states of operation, wherein the optical phase delay  
between the two states differs by half a wavelength  
( $\lambda/2$ ). In the  $+\lambda/4$  state, the retarder **1304** converts  
10 horizontal or vertical linearly polarized light to right-  
handed or left-handed circularly polarized light,  
respectively. Conversely, it will convert right-handed or  
left handed circularly polarized light to horizontal or  
vertical linearly polarized light, respectively. In the  
15  $-\lambda/4$  state, the retarder **1304** converts horizontal or  
vertical linearly polarized light to left-handed or  
right-handed circularly polarized light, respectively,  
and conversely, it will convert right-handed or left  
handed circularly polarized light to vertical or  
20 horizontal linearly polarized light, respectively. Such  
retarder can be either of a nematic or ferroelectric  
type. The nematic type can be made by combining a  $\lambda/4$   
retarder with a  $0-\lambda/2$  wave retarder. There may be other  
ways of constructing a suitable tunable retarder. This  
25 invention contemplates the use of any suitable retarder  
which can be controllably switched between two states,  
with the optical phase delay between the two states  
differing by  $\lambda/2$ .

Furthermore the cholesteric reflector **1303** and  
30 retarder **1304** are oriented with respect to each other



such that in the reflective mode, the cholesteric reflector **1302** reflects light received from the retarder **1304**, as illustrated in FIGS. 13-17. Also, in FIGS. 13-17, the cholesteric reflector **1302** and  $\pm\lambda/4$  retarder **1304** are illustrated as being separated, however, as components of an LCD, these elements would normally be bonded together.

FIG. 13 illustrates the operation of the tunable mirror **1300** in the reflective mode, in which the retarder **1304** is in the  $+\lambda/4$  state **1308**, for converting horizontal linearly polarized light to circularly polarized light of a right rotational direction. Also, the cholesteric reflector reflects right handed circularly polarized light and transmits left handed circularly polarized light. In the simplest case, light having horizontal linear polarization **1312** as indicated by the polarized light vector **1314**, is transmitted through the retarder **1304** and converted to right handed circularly polarized light, as indicated by polarization vector **1316**. The light is then reflected by the cholesteric reflector **1302**, maintaining its polarization **1318**, and is then linearly polarized back through the retarder **1304**, to its original horizontal polarization **1320**. It is also possible for the light entering to have both horizontal and vertical polarizations. In this case, still only the component having horizontal linear polarization will be converted into circularly right handed polarization and reflected back.

FIG. 14 illustrates the operation of the tunable mirror **1300** in the transmissive mode, in which the  $\pm\lambda/4$  retarder **1304** is in the  $-\lambda/4$  state **1400**. First, randomly

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polarized light **1402**, as indicated by the unpolarized light vectors **1404** is transmitted through the cholesteric reflector **1302**, wherein only the left handed circularly polarized component is transmitted, as indicated by the polarized light vector **1406**. Thereafter, the light passes through the retarder **1304** wherein it is linearly polarized to a horizontal linear polarization **1408**.

FIGS. 15 and 16 illustrate the operation of the LCD 1500 which incorporates the tunable mirror 1300. The elements of the LCD 1500 are essentially the same as those in the previous figures, with the exception of the tunable mirror and tunable mirror control. These elements are a liquid crystal cell 1502 located in front of the  $\pm\lambda/4$  retarder 1504 of the tunable mirror 1300; a backlight 1506 which is located behind the cholesteric reflector 1302 of tunable mirror 1300 and can be switched between emissive and non-emissive states; a first polarizer 1508 in front of the cell 1502; a second polarizer 1510 between the cell 1502 and the  $\pm\lambda/4$  retarder 1304; and a control 1520 for the backlight 1506. Again, the liquid crystal cell 1502 is assumed to be a 90° TN cell operating in a normally white mode, and in its ON state wherein it rotates the plane of polarization of linearly polarized light by 90°. Also, for the purpose of illustration, the first and second polarizers 1508 and 1510 have mutually orthogonal planes of polarization 1522 and 1524 in the vertical and horizontal directions, respectively.

FIG. 15 illustrates the LCD 1500 operating in the  
30 reflective mode, in which the  $\pm\lambda/4$  retarder 1304 is in  
the  $+\lambda/4$  state 1308, and the backlight 1506 is in the

**Figure 6.** The effect of the initial concentration of the monomer on the polymerization of **1**. Polymerization conditions: [AIBN] = 0.01 mol/L; [M] = 0.01–0.1 mol/L; [H<sub>2</sub>O] = 0.01 mol/L; [DMSO] = 0.09 mol/L; T = 70 °C; t = 2 h.

non-emissive state 1526. First, randomly polarized ambient light 1528, indicated by unpolarized light vectors 1530, travels through the first polarizer 1508, and is linearly polarized, as indicated by the polarized light vector 1532. The light then travels through the liquid crystal cell 1502, where it is rotated (approximately 90°) to have a plane of polarization approximately parallel to the transmission axis of the second polarizer, as indicated by the polarized light vector 1534, and then passes through the second polarizer 1510, maintaining its linear polarization 1536. The light is then transmitted through the retarder 1304 and is circularly polarized in the right handed direction, as indicated by polarization vector 1538. Thereafter, the light is reflected back by the cholesteric reflector 1302. The light then follows a reversed path with successive polarizations 1540, 1542, 1544, 1546, and 1548 to emerge as an LCD output 1550.

(When the liquid crystal cell is in its OFF state, the  
20 light entering through the first polarizer 1508 travels  
through the cell 1502, where it is rotated to have a  
plane of polarization approximately orthogonal to the  
transmission axis of the second polarizer 1510 and is  
blocked.)

FIG. 16 illustrates the LCD 1500 operating in the reflective mode, in which the retarder 1304 is in the  $-\lambda/4$  state 1400, and the backlight 1506 is in the emissive state 1600. First, randomly polarized backlight emission 1602, indicated by unpolarized light vectors 1604, is transmitted through the reflective polarizer 1302, wherein only the left handed circularly polarized

component is transmitted, as indicated by the polarized light vector **1606**. Thereafter, the light passes through the retarder **1304** wherein it is linearly polarized to a horizontal linear polarization **1608**. The light then  
5 passes through the second polarizer **1510** maintaining its linear polarization **1610**. Its polarization is then rotated by the liquid crystal cell **1502** to an linear polarization **1612**, approximately parallel to the transmitting axis of the first polarizer **1508**. Finally  
10 the light passes through the first polarizer **1508** with linear polarization **1614**, to emerge as the LCD output **1616**. (When the cell is in its OFF state, the light exiting the liquid crystal cell **1502**, has a polarization direction orthogonal to the transmitting axis of the  
15 first polarizer **1508** and is blocked).

As is known in the art, (see Taber, U.S. Pat. No. 5,731,886) the right handed light that is reflected from the cholesteric reflector **1302** will undergo a  $180^\circ$  phase change upon reflection from the backlight surface causing  
20 the right handed circular polarization to change to left handed circular polarization which improves the brightness of the display.

It is also possible to assemble the LCD **1500** without the second polarizer **1510**. This is because the  
25 cholesteric reflector **1302** performs the function of the second polarizer **1510** by filtering out the light not rotated by the liquid crystal cell. FIG.17 illustrates this LCD assembly **1700**.

In addition to the reflective and transmissive modes  
30 described, the LCD and tunable mirror may optionally include an intermediate mode of operation, in which the

006260-8292960

tunable mirror and backlight are operated at intermediate states.

An LCD with a tunable mirror according to any of the embodiments described above may be incorporated into many types of operating systems, including but not limited to: Global Positioning Satellite (GPS) receiver units; computers including the laptop and notepad units; personal digital assistants; calculators; personal calendars; cellular telephones; watches and clocks; automobile, aircraft, and boat displays.

Three examples of operating systems embodying the present invention are shown in FIGS. 18a-18c. FIG. 18a is a cellular telephone 1800 with an LCD 1802, according to the present invention. FIG. 18b is a watch 1804 with an LCD 1806, according to the present invention, and FIG. 18c is a laptop 1808 with an LCD screen 1810 according to the present invention, attached to the keypad section 1812. Since cellular telephones, watches and laptops can be battery operated, using an LCD in accordance with the present invention is desirable as it saves battery life, as well as increase the contrast and brightness of the display.

**I CLAIM:**

1. A liquid crystal display (LCD), comprising:  
a liquid crystal cell; and  
a tunable mirror, optically aligned with the liquid  
crystal cell, having controllable reflective and  
5 transmissive modes, such that in the reflective mode the  
tunable mirror primarily reflects light received from the  
liquid crystal cell back through the cell, and in the  
transmissive mode the mirror primarily transmits light  
towards the liquid crystal cell.
2. The LCD of claim 1, wherein the tunable mirror is  
a reversible electrochemical mirror (REM).
3. The LCD of claim 2, wherein the REM has a matte  
surface to produce a diffuse reflectance.
4. The LCD of claim 1, further comprising a  
backlight on a side of the tunable mirror opposite the  
liquid crystal cell, the backlight being controllably  
switchable between emissive and non-emissive states of  
5 operation, for providing backlighting the LCD in the  
emissive state of operation.
5. The LCD of claim 4, further comprising a first  
linearly polarizing element optically aligned with the

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liquid crystal cell on a side opposite the tunable  
mirror, and having a first plane of polarization in a  
5 first linear direction.

6. The LCD of claim 5, further comprising a second  
linearly polarizing element optically aligned between the  
tunable mirror and the liquid crystal cell, having a  
second plane of polarization in a second linear direction  
5 which is orthogonal to said first plane of polarization.

7. The LCD of claim 6, further comprising:  
a first A-plate between the first polarizing element  
and the liquid crystal cell; and  
a second A-plate between the second polarizing  
5 element and the liquid crystal cell.

8. The LCD of claim 7, further comprising a light  
diffusing element optically aligned with the liquid  
crystal cell for producing a diffused LCD output image.

9. The LCD of claim 8, where the light diffusing  
element is integral with the tunable mirror, such that  
light is diffused upon being reflected by or transmitted  
through the tunable mirror.

10. The LCD of claim 4, further comprising:

006260" 82792960

a first control system for switching the tunable mirror between reflective and transmissive modes; and

a second control system for switching the backlight  
5 between emissive and non-emissive states of operation.

11. The LCD of claim 10, where the first and second controls operate in tandem, such that when the backlight is in the emissive state, the tunable mirror operates in the transmissive mode, and when the backlight is in the  
5 non-emissive state, the tunable mirror operates in the reflective mode.

12. The LCD of claim 11, wherein the first and second controls are automatically responsive to the level of ambient light, such that at a low level of ambient light the backlight operates in the emissive state and  
5 the tunable mirror operates in the transmissive mode, and at a high level of ambient light the backlight operates in the non-emissive state and the tunable mirror operates in the reflective mode.

13. The LCD of claim 12, wherein the first and second controls can be set to be either manually controllable or responsive to ambient light.

14. The LCD of claim 4 wherein:

006260" 82792960



said tunable mirror is further operable at at least one intermediate mode in which it partially reflects light received from the liquid crystal cell back through the cell, and partially transmits light received from the backlight towards the liquid crystal cell; and

said backlight is further operable at at least one intermediate state of operation in which it partially illuminates the LCD.

15. The LCD of claim 4, wherein the tunable mirror comprises:

a quarter-wave ( $\lambda/4$ ) retarder for circularly polarizing linearly polarized light of the second linear direction to circularly polarized light of a second rotational direction, and for linearly polarizing circularly polarized light of the second rotational direction to linearly polarized light of the second linear direction, said  $\lambda/4$  retarder being substantially transmissive to randomly polarized light; and

a liquid crystal reflector optically aligned with said  $\lambda/4$  retarder on a side opposite the liquid crystal cell, said liquid crystal reflector being controllably switchable between transmitting and reflecting states of operation for reflecting circularly polarized light of the second rotational direction in the reflecting state, and for transmitting light in the transmitting state,

such that the tunable mirror operates in the reflective mode when the liquid crystal reflector is in the reflecting state, and in the transmissive mode when

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the liquid crystal reflector is in the transmitting state.

16. The LCD of claim 4, wherein the tunable mirror element comprises:

5 a tunable retarder, being controllably switchable between first and second states of operation, the optical phase delay of the two states differing by  $\lambda/2$ ; and

10 a reflective polarizer optically aligned with the retarder on a side opposite the liquid crystal cell, for reflecting light received from the retarder when the retarder is in the first state and for transmitting light through the retarder when the retarder is in the second state,

15 such that the tunable mirror operates in the reflective mode when the retarder is in the first state, and in the transmissive mode when the retarder is in the second state.

17. The LCD of claim 4, wherein the tunable mirror element comprises:

5 a zero to half-wave ( $0-\lambda/2$ ) retarder, being controllably switchable between  $0\lambda$  and  $\lambda/2$  states of operation, for rotating the plane of polarization of linearly polarized light of the first direction to linearly polarized light of the second direction in the  $\lambda/2$  state, and for transmitting light in the  $0\lambda$  state; and

006260" SET 92960

10 a reflective polarizer optically aligned with the 0- $\lambda/2$  retarder on a side opposite the liquid crystal cell, for reflecting linearly polarized light of the second direction, and for transmitting light having a linear polarization of the first direction,

15 such that the tunable mirror operates in the reflective mode when the 0- $\lambda/2$  retarder is in the  $0\lambda$  state, and in the transmissive mode when the 0- $\lambda/2$  retarder is in the  $\lambda/2$  state.

18. The LCD of claim 17, wherein the 0- $\lambda/2$  retarder is a nematic liquid crystal retarder.

20. The LCD of claim 17, further comprising a quarter-wave ( $\lambda/4$ ) retarder between the backlight and tunable mirror.

21. The LCD of claim 17, further comprising a light diffusing element optically aligned with the liquid crystal cell for producing a diffused LCD output image.

22. The LCD of claim 4, wherein the tunable mirror comprises:

a tunable retarder, being controllably switchable between first and second states of operation, the optical  
5 phase delay of the two states differing by  $\lambda/2$ ; and

006260" 8879/960

a cholesteric reflector optically aligned with the retarder on a side opposite the liquid crystal cell, for reflecting light received from the retarder in the first state, and for transmitting light through the retarder in  
 10 the second state.

such that the tunable mirror operates in the reflective mode when the retarder is in the first state, and in the transmissive mode when the retarder is in the second state.

23. The LCD of claim 22, wherein the tunable retarder is a negative quarter-wave to positive quarter-wave ( $\pm\lambda/4$ ) retarder, controllably switchable between  $-\lambda/4$  and  $+\lambda/4$  states of operation,

5 whereby in the  $+\lambda/4$  state, said retarder converts linearly polarized light of a second linear direction to circularly polarized light of a second rotational direction, and converts circularly polarized light of the second rotational direction to linearly polarized light  
 10 of the second linear direction and, in the  $-\lambda/4$  state, said retarder converts circularly polarized light of a first rotational direction to linearly polarized light of the second linear direction; and

whereby said cholesteric reflector reflects  
 15 circularly polarized light of the second rotational direction and transmits a component of randomly polarized light having a circular polarization of the first rotational direction,

such that the tunable mirror operates in the  
 20 reflective mode when the  $\pm\lambda/4$  retarder is in the  $+\lambda/4$

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state, and in the transmissive mode when the  $\pm \lambda/4$  retarder is in the  $-\lambda/4$  state.

24. The LCD of claim 23, wherein the  $\pm \lambda/4$  retarder comprises a quarter-wave ( $\lambda/4$ ) retarder optically aligned with a zero to half-wave ( $0-\lambda/2$ ) retarder.

25. The LCD of claim 23, wherein the cholesteric reflector is a diffuse reflecting cholesteric liquid crystal film.

*polymer* *BEW 9/28/00*  
*4/6 9/28/00*

26. The LCD of claim 23, wherein the  $\pm \lambda/4$  retarder is a ferroelectric liquid crystal retarder.

27. A tunable mirror, comprising:

a quarter-wave ( $\lambda/4$ ) retarder for circularly polarizing linearly polarized light of a first linear direction to circularly polarized light of a first rotational direction, and for linearly polarizing circularly polarized light of the first rotational direction to linearly polarized light of the first linear direction, said  $\lambda/4$  retarder being substantially transmissive to randomly polarized light; and

10 a liquid crystal reflector optically aligned with said  $\lambda/4$  retarder, said liquid crystal reflector being

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controllably switchable between reflecting and transmitting states of operation for reflecting circularly polarized light of the first rotational  
 15 direction in the reflecting state, and for transmitting light in the transmitting state,

such that the tunable mirror reflects linearly polarized light of the first linear direction entering the  $\lambda/4$  retarder from a side opposite the liquid crystal  
 20 reflector when the liquid crystal reflector is in the reflecting state, and transmits light entering the liquid crystal reflector from a side opposite the circularly polarizing element when the liquid crystal reflector is in the transmitting state.

28. A tunable mirror comprising:

a zero to half-wave ( $0-\lambda/2$ ) retarder, being controllably switchable between  $0\lambda$  and  $\lambda/2$  states of operation, for rotating the plane of polarization of  
 5 linearly polarized light of a first direction to linearly polarized light of a second direction in the  $\lambda/2$  state, and for transmitting light in the  $0\lambda$  state; and

a reflective polarizer optically aligned with the  $0-\lambda/2$  retarder, for reflecting linearly polarized light  
 10 of the second direction received from the retarder, back through the retarder, and for transmitting light having a linear polarization of the first direction towards the retarder,

such that the tunable mirror reflects linearly  
 15 polarized light of the second direction received through

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the  $0-\lambda/2$  retarder from a side opposite the reflective polarizer when the  $0-\lambda/2$  retarder is in the  $0\lambda$  state, and transmits light having a linear polarization of the first direction received through the reflective polarizer from  
 20 a side opposite the  $0-\lambda/2$  retarder, when the  $0-\lambda/2$  retarder is in the  $\lambda/2$  state.

29. The tunable mirror of claim 28 wherein the  $0-\lambda/2$  retarder is a nematic liquid crystal retarder.

30. A tunable mirror comprising:

a negative quarter-wave to positive quarter-wave ( $\pm\lambda/4$ ) retarder, being controllably switchable between  $-\lambda/4$  and  $+\lambda/4$  states of operation,

5 whereby in the  $+\lambda/4$  state, said retarder circularly polarizes linearly polarized light of a first linear direction to circularly polarized light of a first rotational direction, and linearly polarizes circularly polarized light of the first rotational direction to  
 10 linearly polarized light of the first linear direction, and, in the  $-\lambda/4$  state, said retarder linearly polarizes circularly polarized light of a second rotational direction to linearly polarized light of the first linear direction; and

15 a cholesteric reflector optically aligned with the  $\pm\lambda/4$  retarder, for reflecting circularly polarized light received from the  $\pm\lambda/4$  retarder having a polarization of the first rotational direction, back

006260" 8T9/960

through the  $\pm \lambda/4$  retarder, and transmitting circularly  
20 polarized light of the second rotational direction  
towards the  $\pm \lambda/4$  retarder,

such that the tunable mirror reflects linearly  
polarized light of the first linear direction, received  
through the  $\pm \lambda/4$  retarder from a side opposite the  
25 cholesteric reflector when the  $\pm \lambda/4$  retarder is in the  
 $+\lambda/4$  state, and transmits circularly polarized light of  
the second rotational direction received through the  
cholesteric reflector, on a side opposite the  $\pm \lambda/4$   
retarder when the  $\pm \lambda/4$  retarder is in the  $-\lambda/4$  state.

31. The tunable mirror of claim 30, wherein the  
cholesteric reflector is a diffuse reflecting cholesteric  
liquid crystal film.

32. The tunable mirror of claim 31, wherein the  $\pm \lambda/4$   
 $\lambda/4$  retarder comprises a  $0-\lambda/2$  retarder and a  $\lambda/4$   
retarder.

33. A method of operating a liquid crystal display  
(LCD), comprising:

primarily reflecting light entering a first side of  
a liquid crystal cell and exiting a second side of said  
5 liquid crystal cell back through the liquid crystal cell  
when the amount of light entering from the first side of

006260" BCT 9/960



the liquid crystal cell is above a viewability threshold;  
and

generating and primarily transmitting a backlight  
10 emission from the second side of the liquid crystal cell  
through the liquid crystal cell when the amount of light  
entering from the first side of the liquid crystal cell  
falls below said viewability threshold.

34. The method of claim 33, wherein the primarily  
reflecting step comprises:

linearly polarizing randomly polarized light  
entering from the first side of the liquid crystal cell  
5 to a first direction of polarization;

selectively rotating the light thus linearly  
polarized to a second direction of polarization, the  
first and second directions of polarization being  
mutually orthogonal; and

10 selectively reflecting the light having the second  
direction of polarization, but not the light having the  
first direction of polarization, back through the liquid  
crystal cell.

35. The method of claim 34, wherein the selectively  
reflecting step comprises:

transmitting the light having the second direction  
of polarization, but not the light having the first  
5 direction of polarization; and

reflecting said light having the second direction of  
polarization back through the liquid crystal cell.

005260" SET 9/96

polarizing the generated backlight emission to said second direction of linear polarization; and

5 selectively rotating the light having the second direction of linear polarization to the first direction of linear polarization.

38. The method of claim 37, further comprising:  
diffusing the light transmitted through the LCD to  
produce a diffused LCD output image.

primarily reflecting light entering a first side of a liquid crystal cell and exiting a second side of the liquid crystal cell back through the liquid crystal cell when the amount of light entering from the first side of the liquid crystal cell is above a viewability threshold; generating and primarily transmitting a backlight emission from the second side of the liquid crystal cell

10 through the liquid crystal cell when approximately no  
light enters the first side of the liquid crystal cell;  
and

partially reflecting light entering a first side of  
a liquid crystal cell and exiting a second side of the  
15 liquid crystal cell back through the liquid crystal cell,  
and generating and partially transmitting a backlight  
emission from the second side of the liquid crystal cell  
through the liquid crystal cell when light entering from  
the first side of the liquid crystal cell falls below  
20 said viewability threshold, said backlight emission being  
generated in an amount sufficient to supplement the  
reflected light such that it reaches said viewability  
threshold.

40. A method of operating a liquid crystal display  
(LCD) comprising:

transmitting linearly polarized light entering a  
first side of a liquid crystal cell, through the liquid  
5 crystal cell, said linearly polarized light having a  
first direction of linear polarization;

selectively rotating while transmitting said  
polarized light through the liquid crystal cell to a  
second direction of linear polarization, said second and  
10 first directions of linear polarization being mutually  
orthogonal;

circularly polarizing the linearly polarized light  
having the second direction of linear polarization to a  
circular polarization of a second rotational direction;  
15 and

0066360" SET 92960

reflecting the circularly polarized light having the circular polarization of the second rotational direction, back through the liquid crystal cell, when the amount of light entering the first side of the liquid crystal cell  
20 is above a predetermined viewability threshold.

41. The LCD method of claim 40, further comprising transmitting the linearly polarized light having the second direction of linear polarization, and absorbing the light having the first direction of linear  
5 polarization, before circularly polarizing said linearly polarized light having the second direction of linear polarization.

42. The LCD method of claim 40, further comprising:  
generating a backlight emission on a side of the liquid crystal cell opposite the first side, when the amount of light entering the first side of the liquid  
5 crystal cell is below a predetermined viewability threshold;

linearly polarizing the backlight emission to the second direction of linear polarization; and

selectively rotating while transmitting said  
10 backlight emission entering on a side of the liquid crystal cell opposite the first, and having the second direction of linear polarization, through the liquid crystal cell, to the first direction of linear polarization.

006260" 88792950

43. The LCD method of claim 42, further comprising transmitting the light exiting said first side of the liquid crystal cell and having the first direction of polarization, but not the second, to the LCD output.

44. An LCD method comprising:

transmitting linearly polarized light entering a first side of a liquid crystal cell, through the liquid crystal cell, said linearly polarized light having a first direction of linear polarization;

selectively rotating while transmitting said polarized light through the liquid crystal cell to a second direction of linear polarization, said second and first directions of linear polarization being mutually orthogonal;

transmitting said polarized light having the second direction of linear polarization, but not the first; and

reflecting said polarized light having the second direction of linear polarization back through the liquid crystal cell when the amount of light entering the first side of the liquid crystal cell is above a viewability threshold.

45. The LCD method of claim 44, further comprising:

generating a backlight emission on a side of the liquid crystal cell opposite the first side, when the amount of light entering the first side of the liquid

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5 crystal cell is below the predetermined viewability threshold;

transmitting a component of said backlight emission having a linear polarization of the first direction;

10 rotating said light having the linear polarization of the first direction to the linear polarization of the second direction; and

selectively rotating said light having the linear polarization of the second direction, to a linear polarization of the first direction, while transmitting  
15 said light through the liquid crystal cell.

46. The LCD method of claim 45, further comprising transmitting the light exiting said first side of the liquid crystal cell and having the first direction of polarization, but not the second, to the LCD output.

47. The LCD method of claim 44, further comprising:  
diffusing the light transmitted through the LCD to produce a diffused LCD output image.

48. An LCD method comprising:

transmitting linearly polarized light entering a first side of a liquid crystal cell, through the liquid crystal cell, said linearly polarized light having a  
5 first direction of linear polarization;

selectively rotating while transmitting said polarized light having the first direction of linear

006260-85792950

006260" SET 9/960

polarization, through the liquid crystal cell, to a  
second direction of linear polarization, said second and  
10 first directions of linear polarization being mutually  
orthogonal;

circularly polarizing said light having the linear  
polarization of the second direction to a linear  
polarization of a second rotational direction when the  
15 level of light entering  
the first side of the liquid crystal cell is above a  
viewability threshold; and

reflecting said polarized light having the circular  
polarization of the second rotational direction towards  
20 the liquid crystal cell.

49. The LCD method of claim 48, further comprising  
transmitting the polarized light having the second  
direction of linear polarization, but not the first,  
after selectively rotating said polarized light having  
5 said first direction of linear polarization.

50. The LCD method of claim 49, further comprising:  
linearly polarizing said reflected polarized light  
having the circular polarization of the second rotational  
direction, to a linear polarization of the second  
5 direction, after reflecting said light towards the liquid  
crystal cell;

selectively rotating while transmitting said  
linearly polarized light through the liquid crystal cell,  
to a linear polarization of the first direction.

51. The LCD method of claim 50, further comprising:  
generating a backlight emission when the level of  
light entering the first side of the liquid crystal cell  
falls below the predetermined viewability threshold;

5 transmitting the component of said backlight having  
a circular polarization of a first rotational direction;  
linearly polarizing said light to a polarization of  
the second direction; and

10 selectively rotating while transmitting said light  
through the liquid crystal cell to a linear polarization  
of the first direction.

52. The LCD method of claim 51, further comprising  
transmitting the light exiting said first side of the  
liquid crystal cell and having the first direction of  
polarization, but not the second, to the LCD output.

53. A display system, comprising:  
an operating system and  
a liquid crystal display (LCD) connected to said  
operating system to display a characteristic of said  
5 operating system, said LCD comprising:  
a liquid crystal cell;  
a tunable mirror optically aligned with the liquid  
crystal cell, having controllable reflective and  
transmissive modes,

006260" SET 92950



10 a backlight on a side of the tunable mirror opposite  
the liquid crystal cell, the backlight being controllably  
switchable between on and off states of operation such  
that, in the reflective mode, the tunable mirror  
primarily reflects light received from the liquid crystal  
15 cell back through the cell, and in the transmissive mode  
the mirror primarily transmits light received from the  
backlight towards the liquid crystal cell; and

a first linearly polarizing element optically  
aligned with the liquid crystal cell on a side opposite  
20 the tunable mirror, and having a first plane of  
polarization in a first linear direction.

54. The display system of claim 53, further  
comprising a second polarizing element optically aligned  
between the tunable mirror and the liquid crystal cell,  
having a second plane of polarization in a second linear  
5 direction which is orthogonal to said first plane of  
polarization.

55. A method of operating a tunable mirror,  
comprising:

primarily reflecting light of a first polarization  
from the tunable mirror when it is in a reflective mode;  
5 and

primarily transmitting light of a second  
polarization through the tunable mirror when it is in a  
transmissive mode.

56. The method of claim 55, further comprising polarizing randomly polarized light to said first polarization before primarily reflecting the light.

57. The method of claim 56, wherein said first polarization is a circular polarization of a first rotational direction.

58. The method of claim 57, wherein said second polarization is random polarization.

59. The method of claim 56, wherein said first polarization is a linear polarization of a first direction.

60. The method of claim 59, further comprising polarizing randomly polarized light to said first polarization, before primarily reflecting said first polarization light.

61. The method of claim 60, further comprising polarizing randomly polarized light to said second direction, and primarily transmitting said second direction light.

006250" 006250"

62. The method of claim 61, wherein said second polarization is a linear polarization of a second direction, orthogonal to said first direction.

63. The method of claim 62, wherein said primarily transmitting step further comprises rotating by  $90^\circ$  after polarizing said randomly polarized light to said second direction, such that said light is rotated to the polarization of the first direction.

64. The method of claim 55, wherein the primarily transmitting step further comprises converting light of said second polarization to said first polarization.

65. The method of claim 64, wherein said first polarization is a linear polarization in a first direction.

66. The method of claim 65, wherein the primarily reflecting step comprises:

converting the light having said linear polarization  
of said first direction to a circular polarization of a  
5 first rotational direction;

reflecting the light having said circular polarization of said first rotational direction; and

converting the light having said circular  
polarization of said first rotational direction back to a  
10 linear polarization in said first direction.

67. The mirror method of claim 66, wherein said  
second polarization is a circular polarization of a  
second rotational direction.

68. The mirror method of claim 67, further  
comprising converting randomly polarized light to said  
second polarization before primarily transmitting said  
light.

69. The mirror method of claim 68, further  
comprising converting randomly polarized light to said  
first direction of polarization before primarily  
reflecting said light.

HIGH BRIGHTNESS TRANSFLECTIVE LCD AND METHOD USING  
TUNABLE MIRROR

5 ABSTRACT OF THE DISCLOSURE

A Liquid Crystal Display (LCD) uses a tunable mirror in place of a partially reflective mirror. The tunable mirror has a controllable reflectivity and transmittance which allows the mirror to primarily reflect light when  
10 the LCD is operated in a reflective mode, and to primarily transmit light from a backlight when the LCD is operated in a transmissive mode.

006250" SET 9/2/86

FIGURE 1 (LCD IN REFLECTIVE STATE)

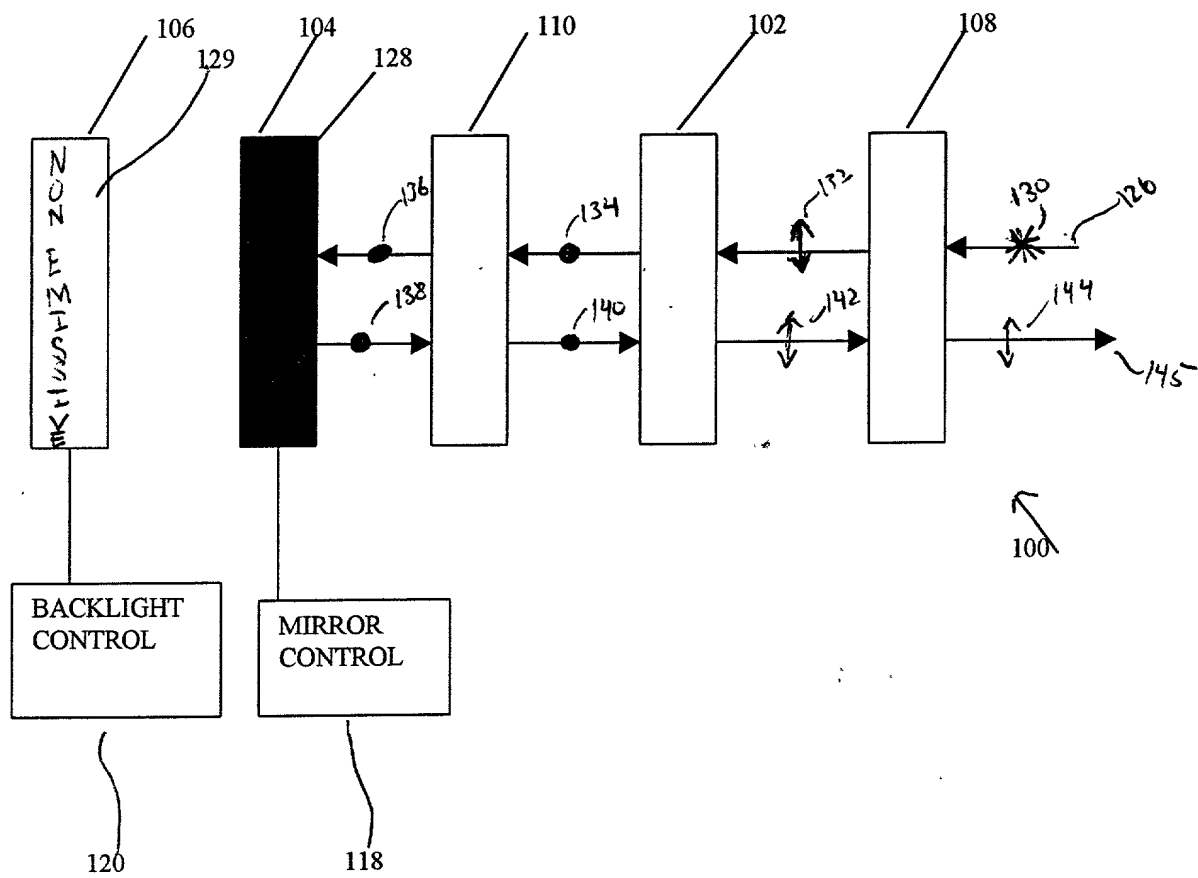


FIGURE 2 (LCD IN TRANSMISSIVE STATE)

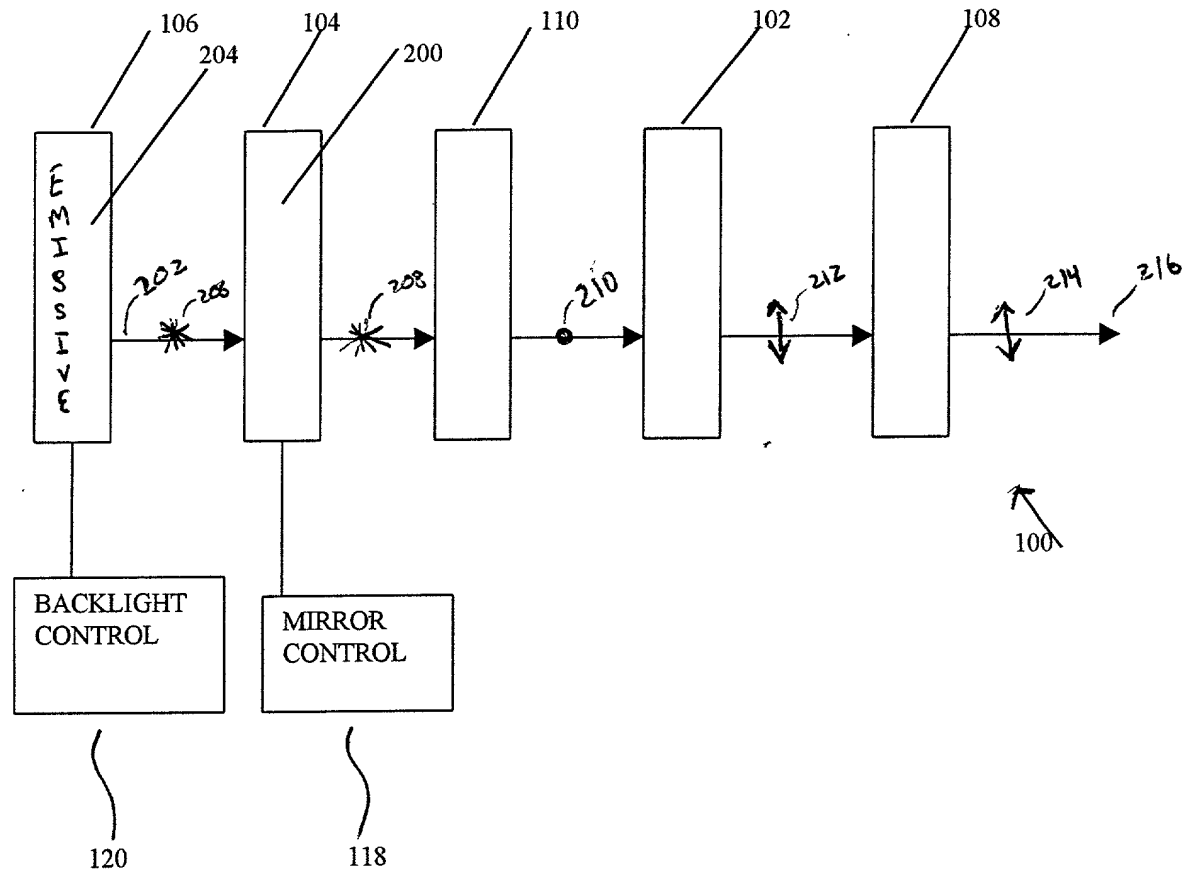


FIGURE 3

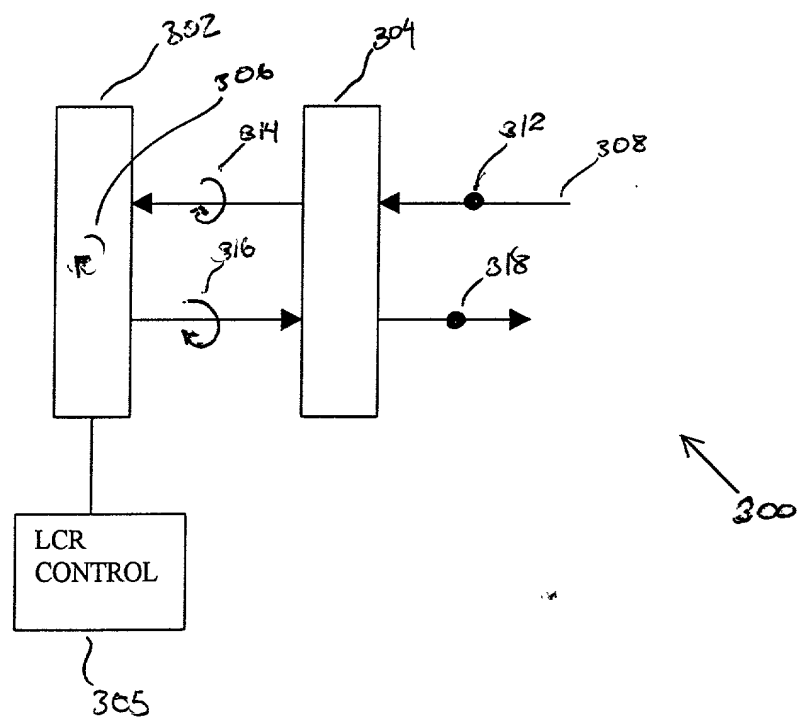




FIGURE 4

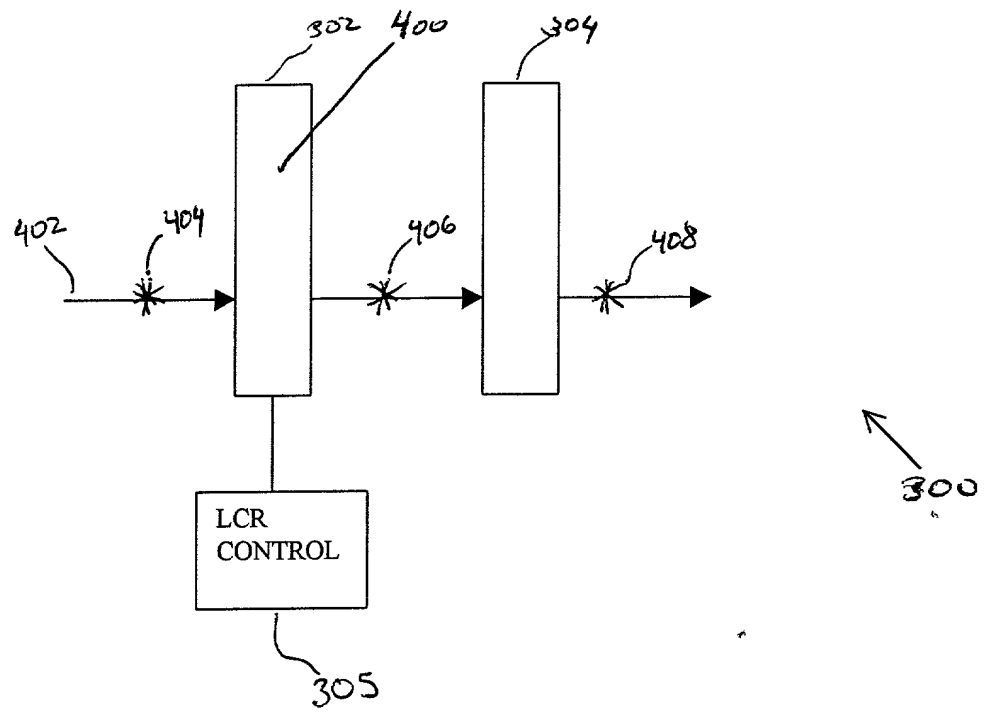


FIGURE 5

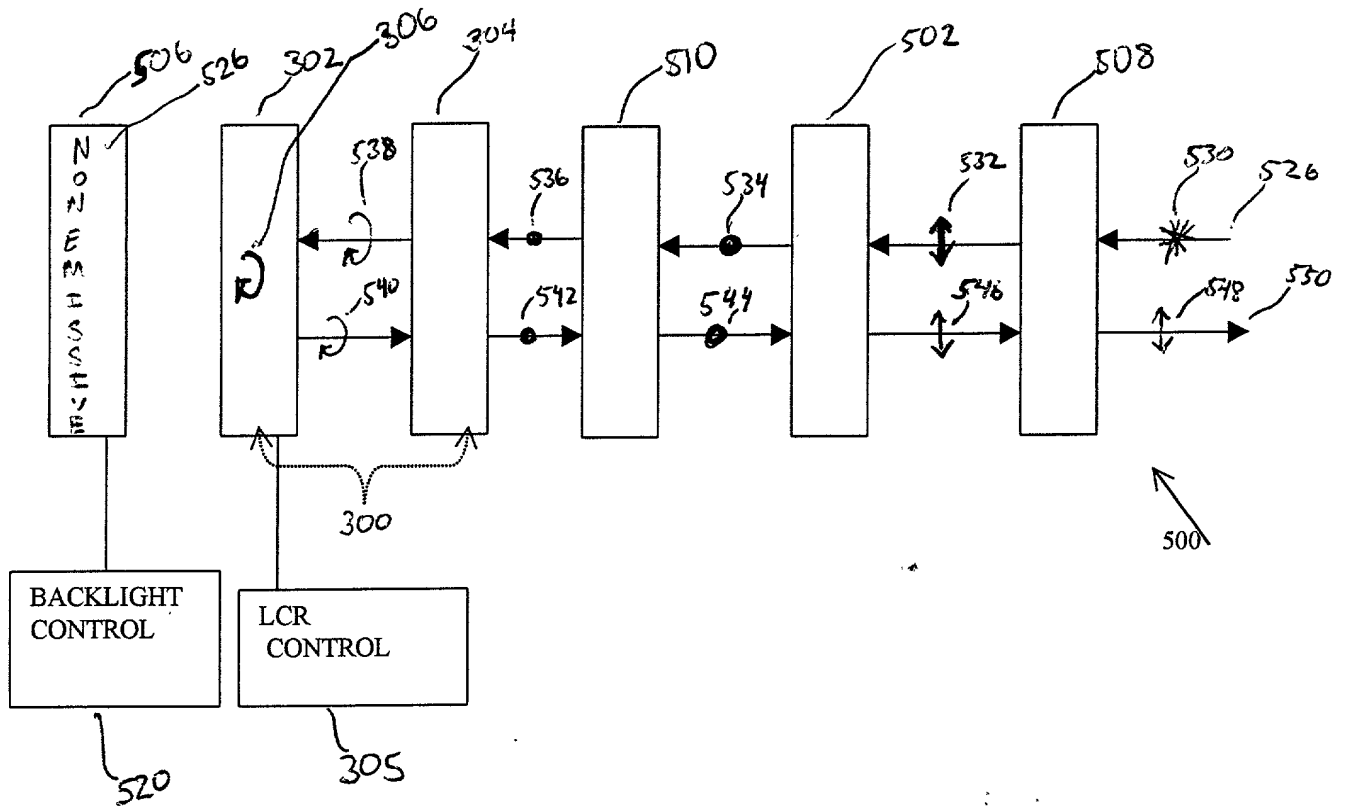


FIGURE 6

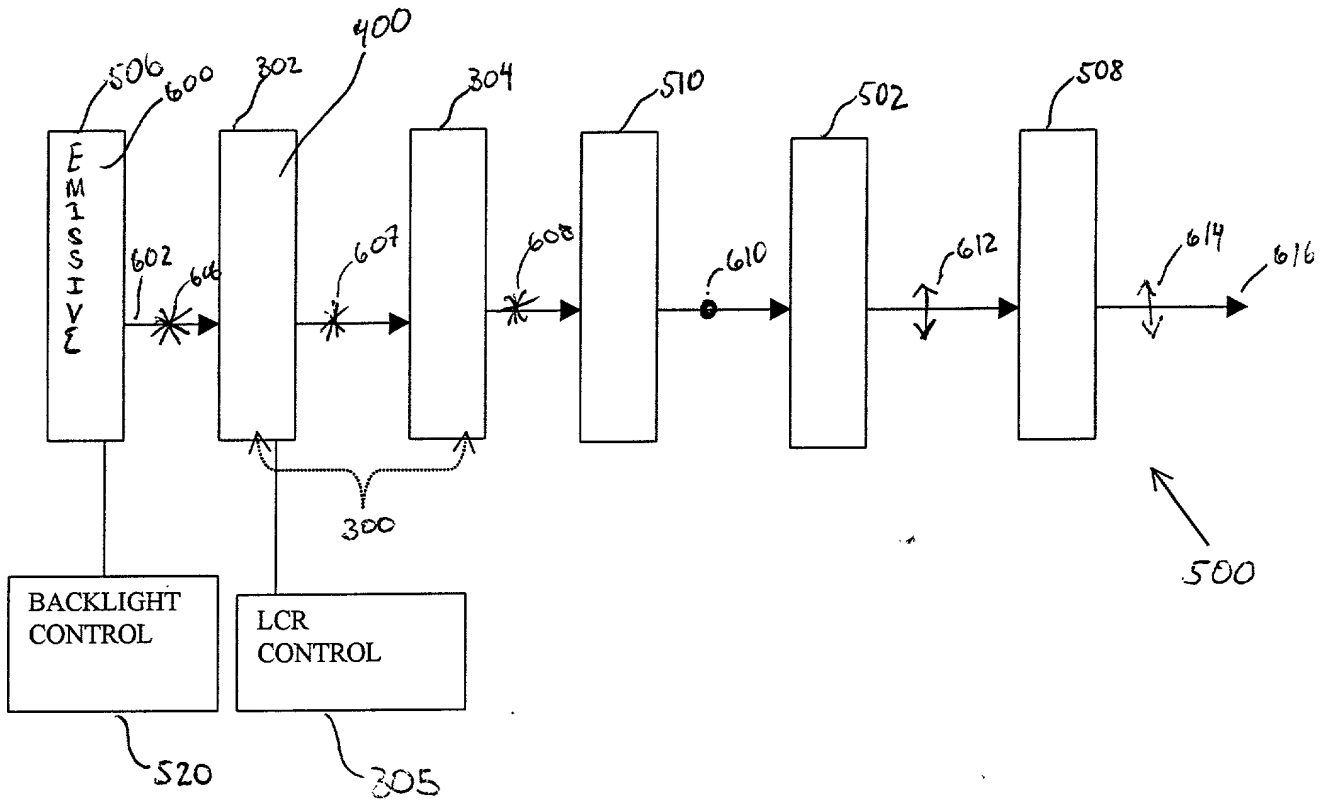


FIGURE 7

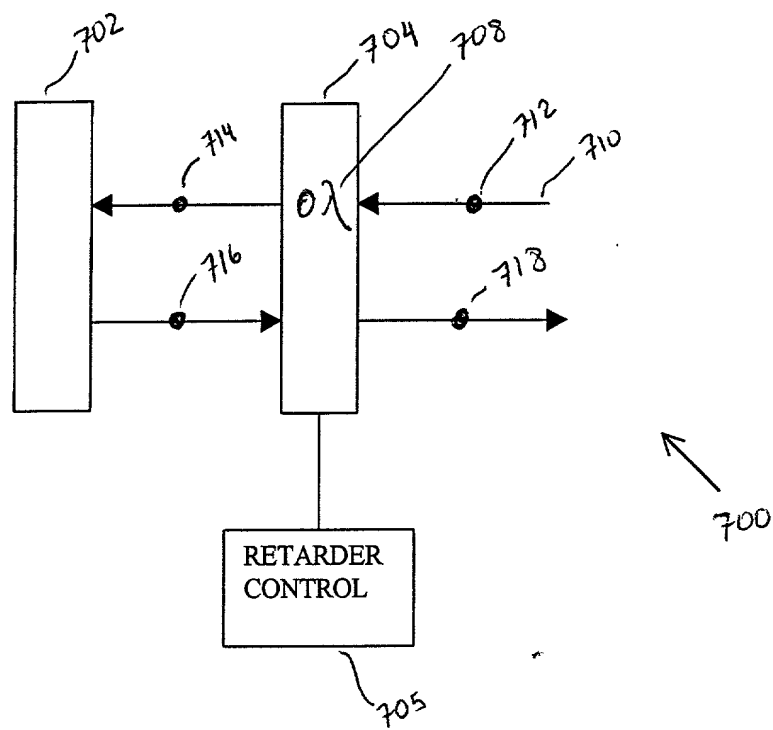


FIGURE 8

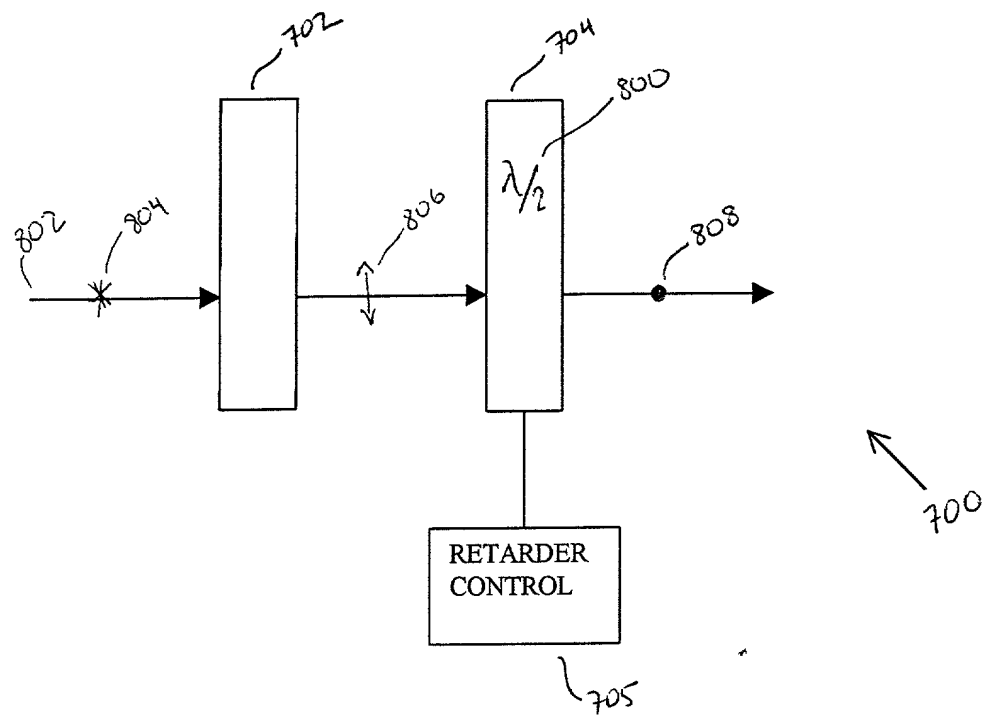


FIGURE 9

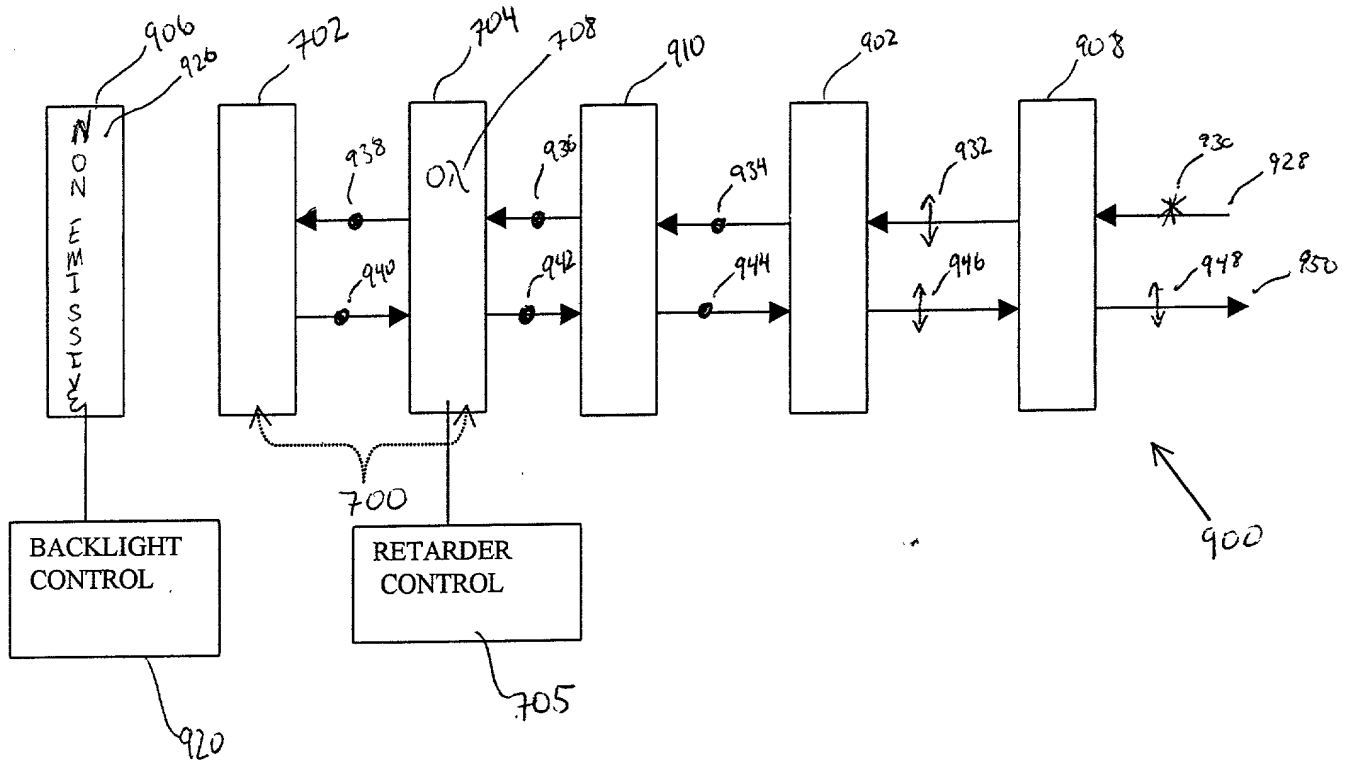


FIGURE 10

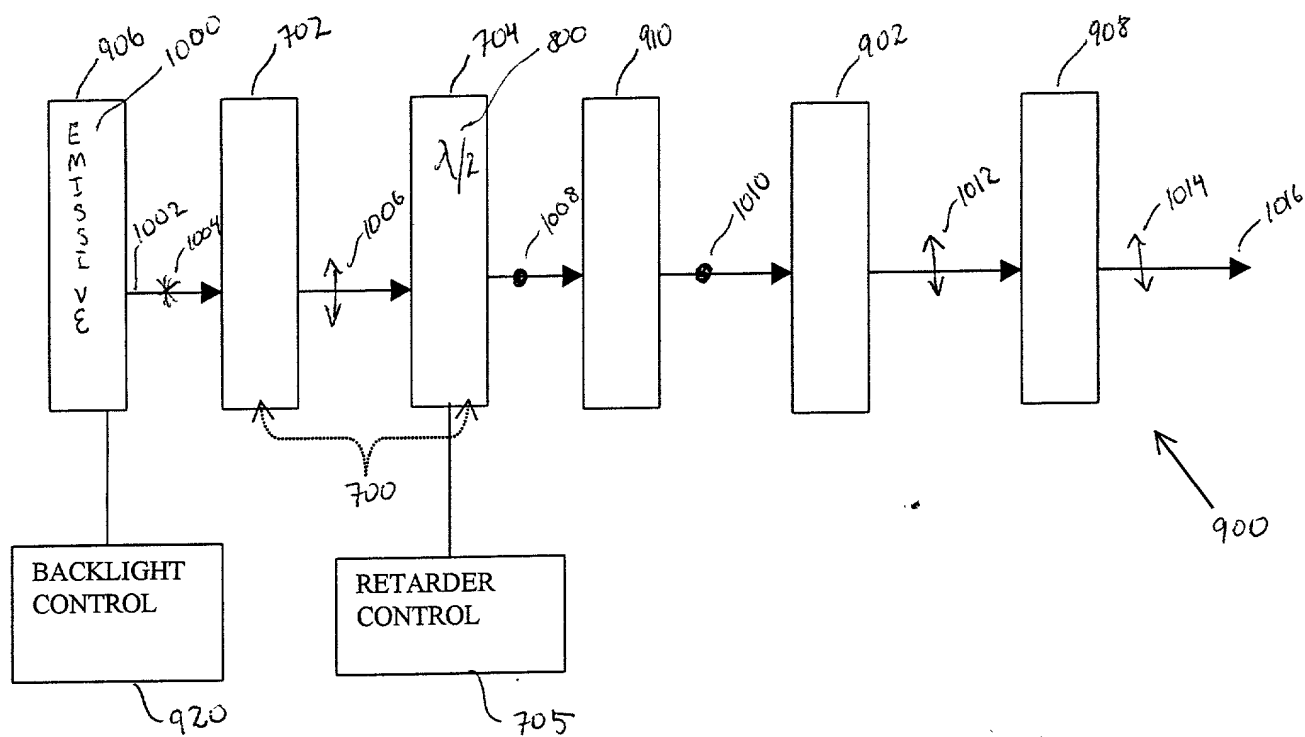


FIGURE 11

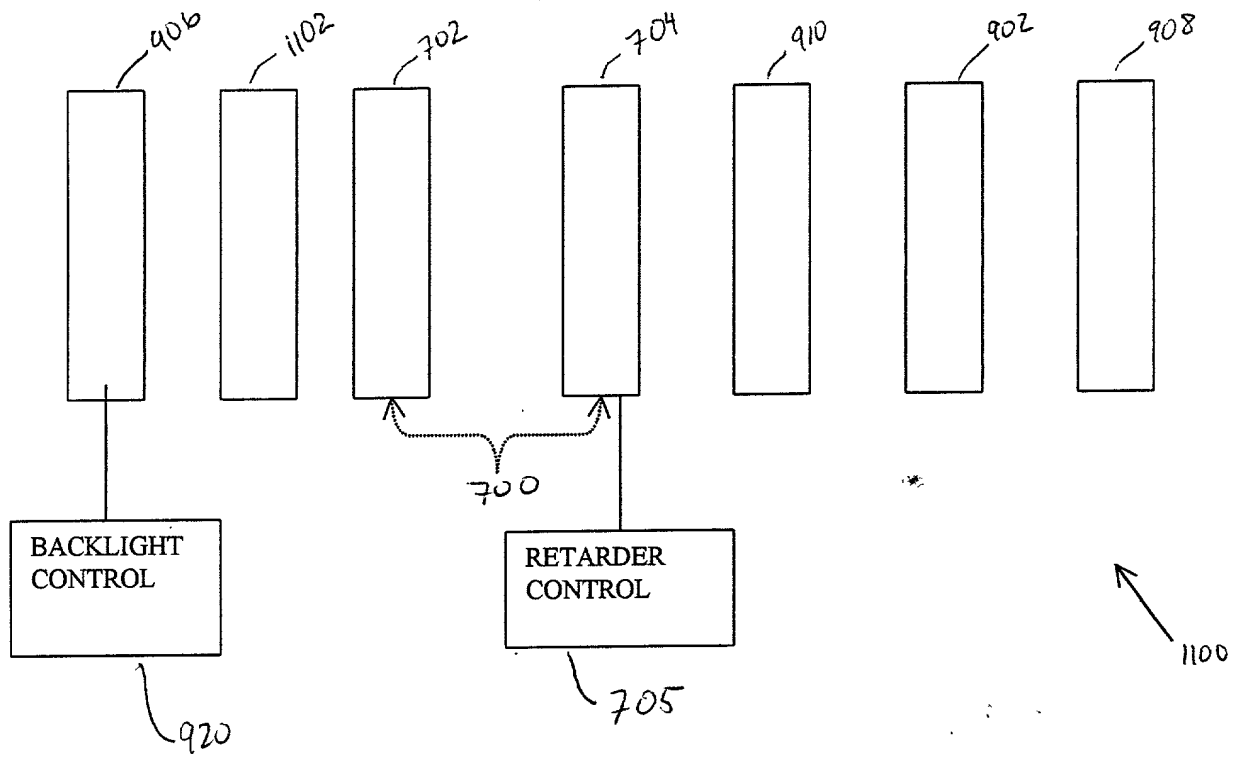




FIGURE 12

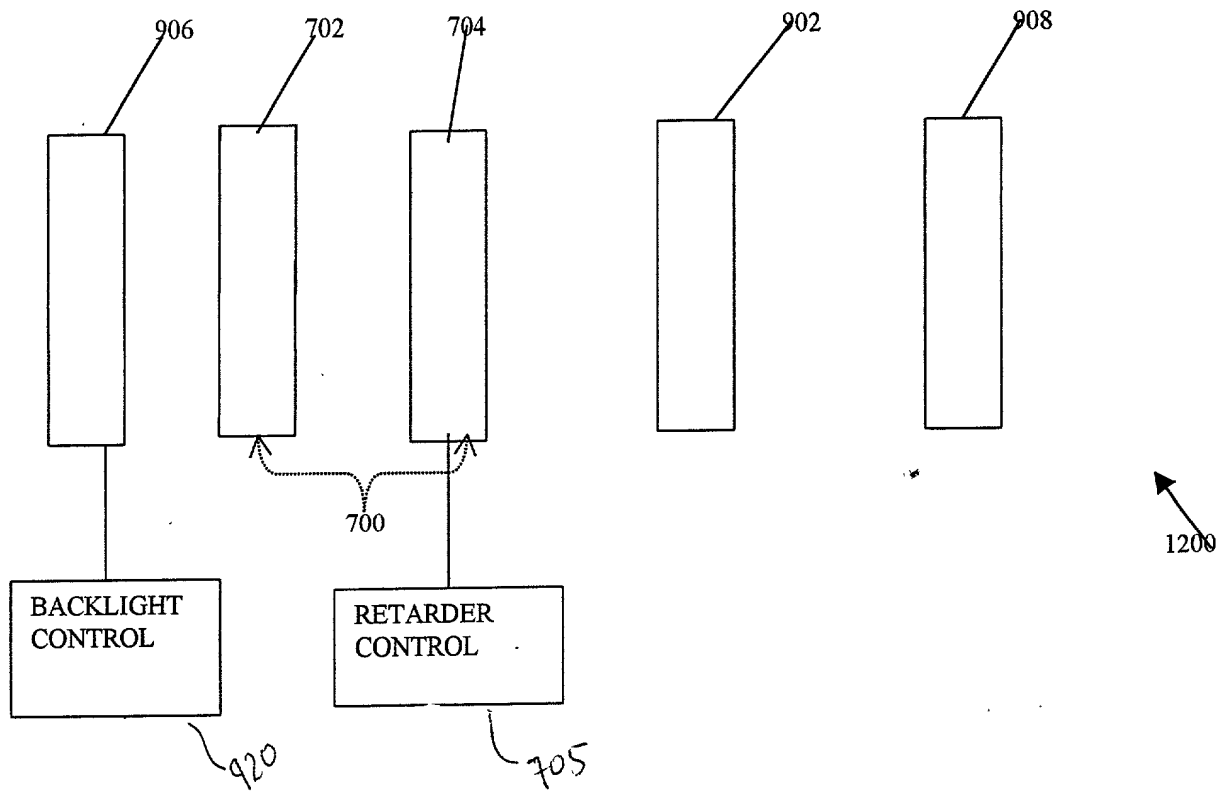


FIGURE 13

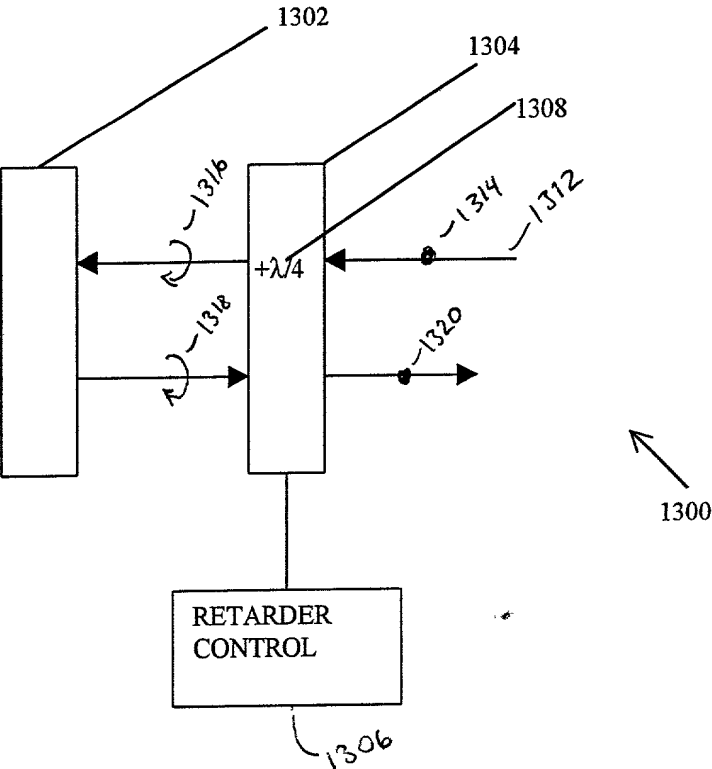
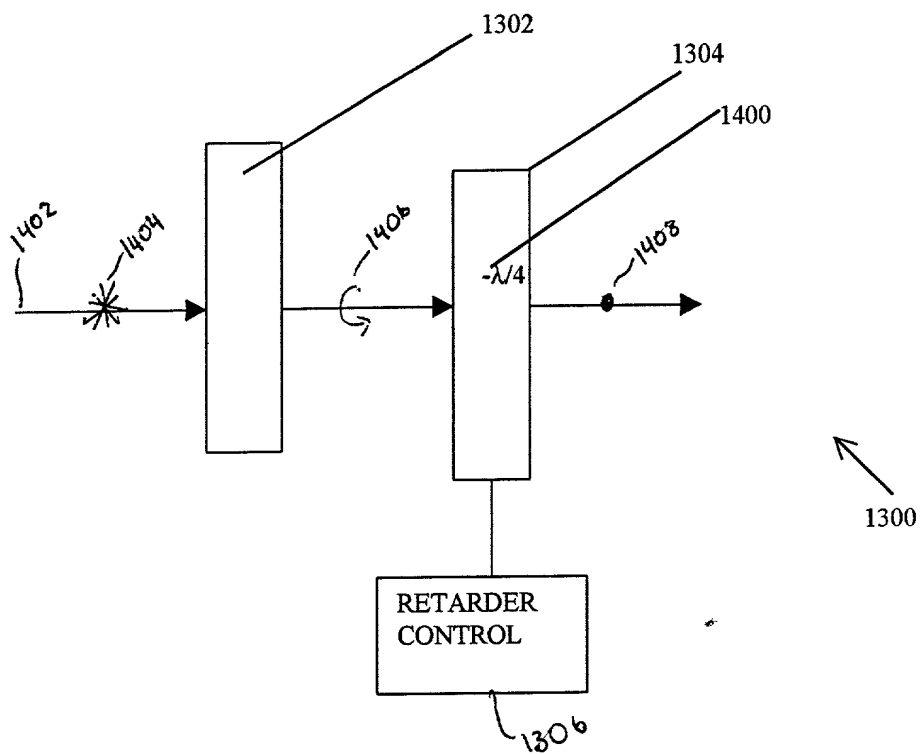


FIGURE 14



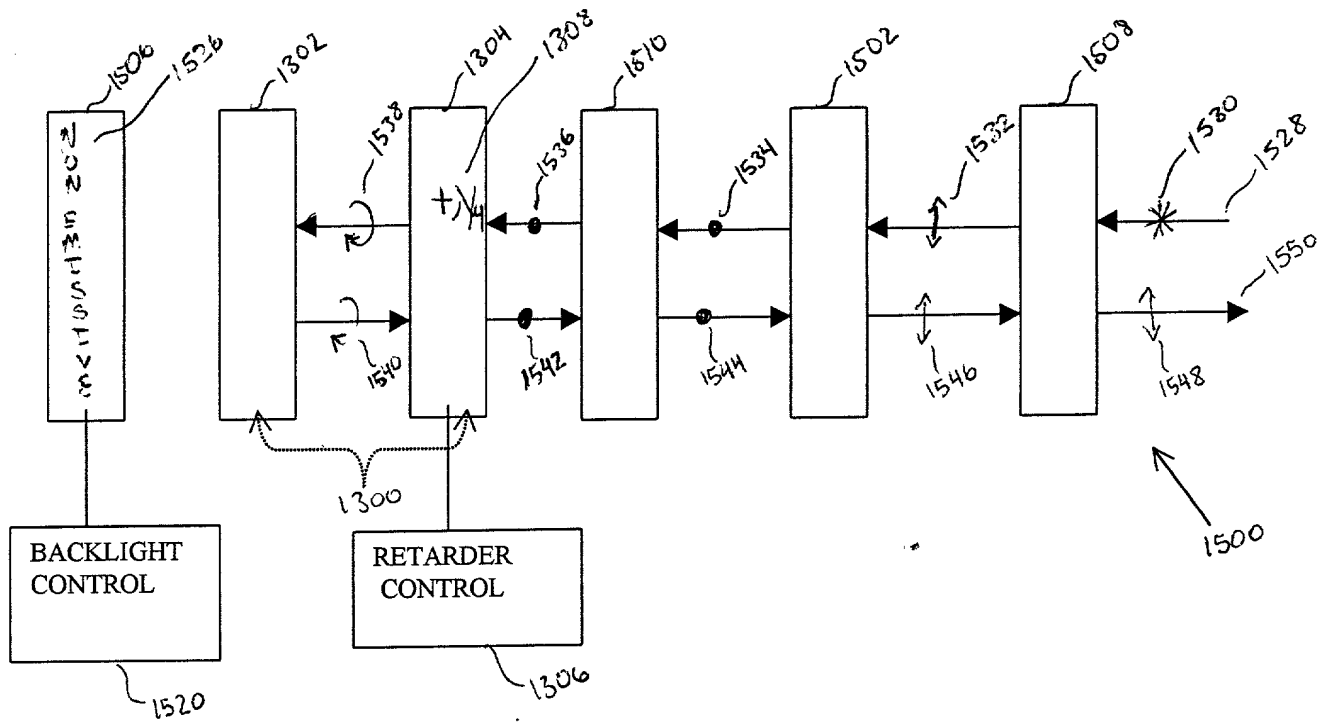
[illegible]

FIGURE 16

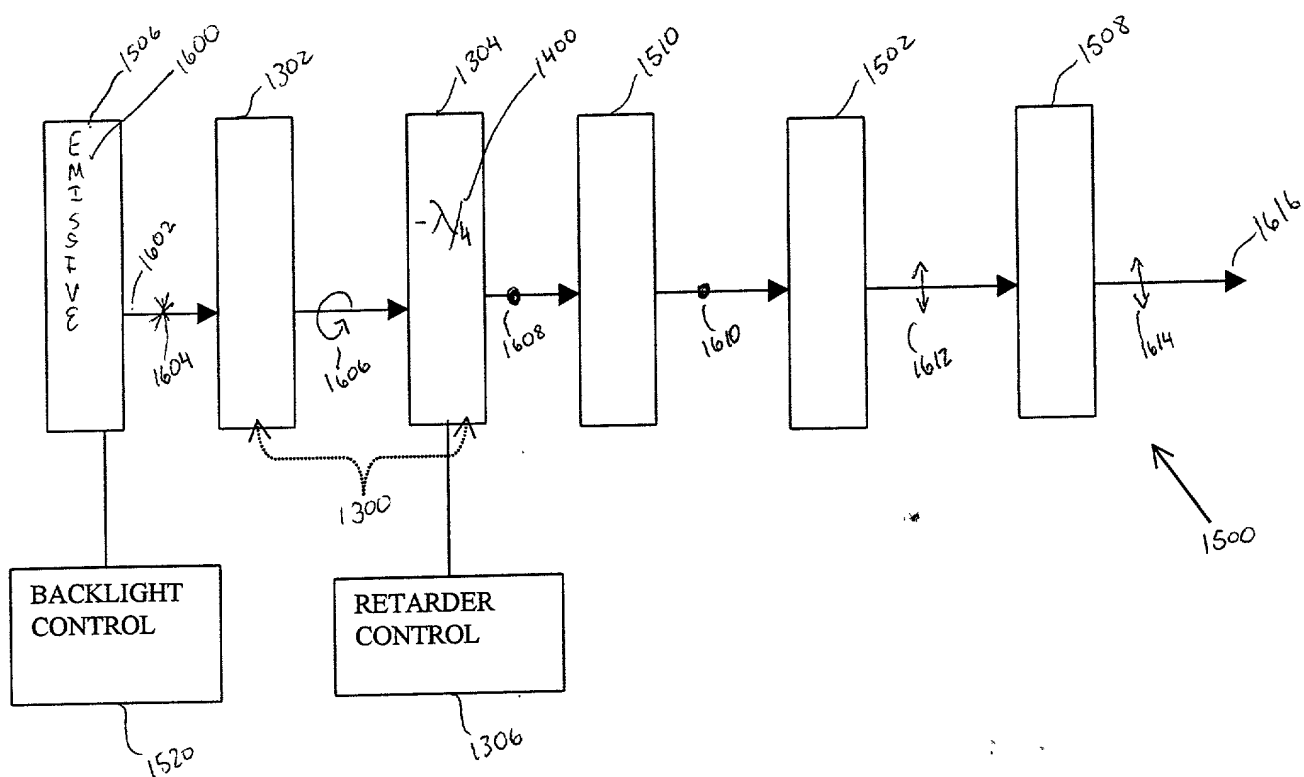
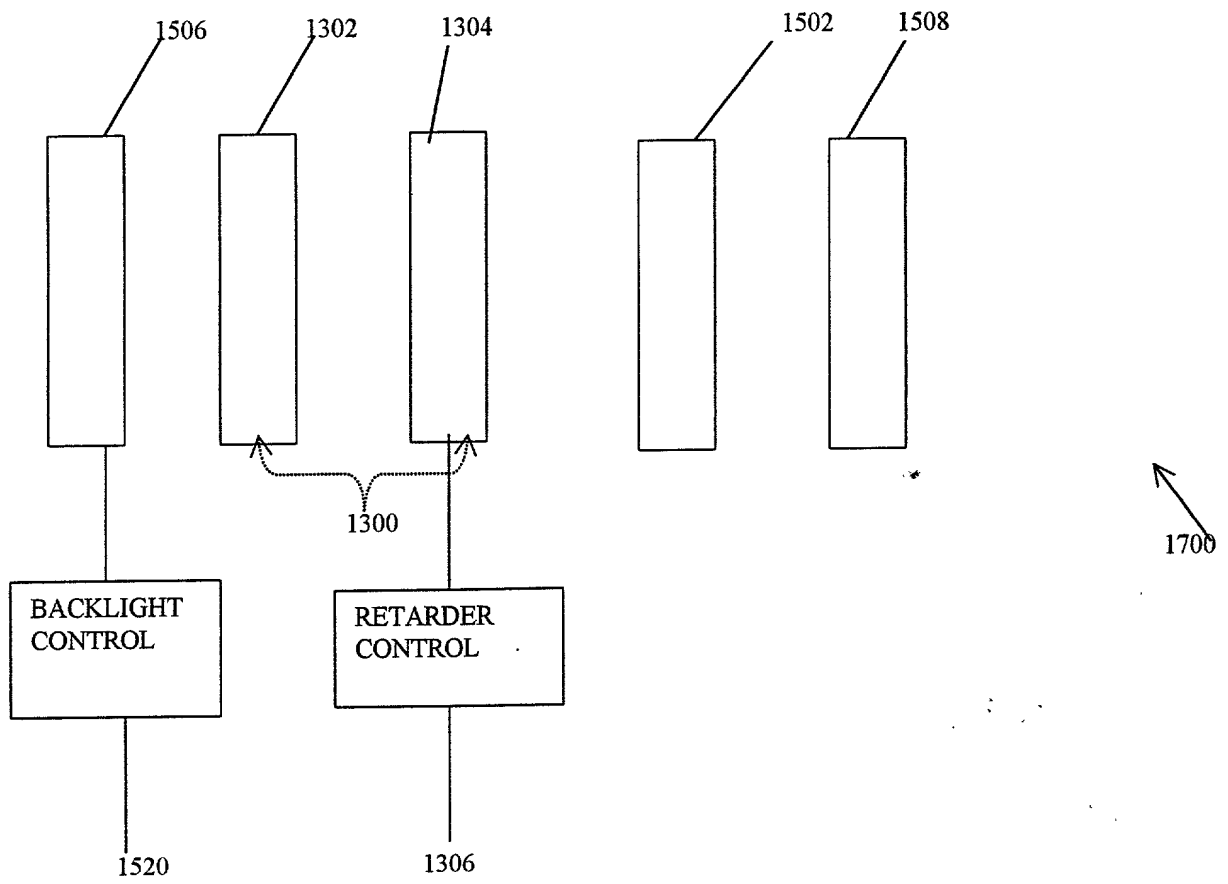


FIGURE 17



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Fig. 18 a

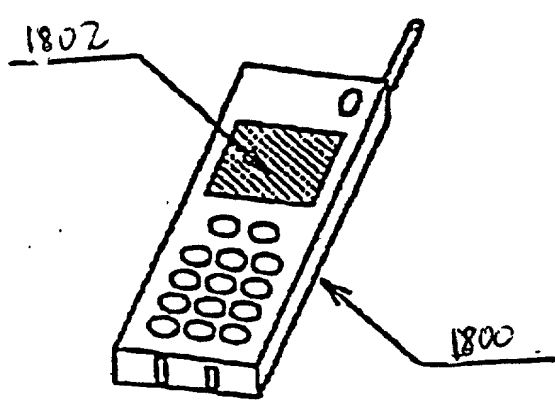


Fig. 18 b

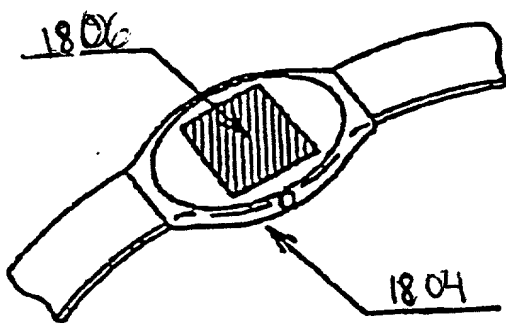
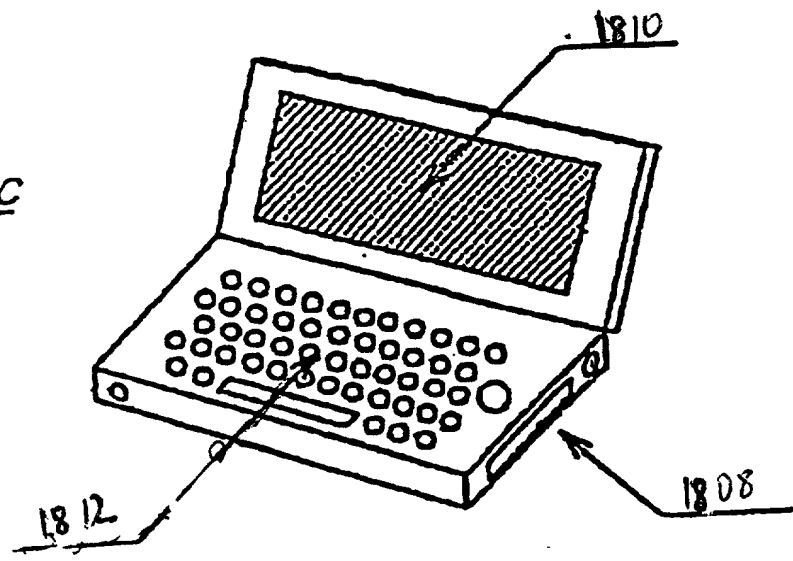


Fig. 18 c



DECLARATION AND POWER OF ATTORNEY

As a below named inventor, I hereby declare that:

My address, residence, and citizenship are as stated below next to my name.

I believe I am the original, first, and sole inventor of the subject matter which is claimed and for which a patent is sought on the invention entitled HIGH BRIGHTNESS TRANSFLECTIVE LCD AND METHOD USING TUNABLE MIRROR, the specification of which is attached hereto.

I have reviewed and understand the contents of the above identified specification, including the claims.


I acknowledge my duty to disclose all information known to me to be material to patentability as defined in 37 CFR § 1.56.


I hereby appoint the following attorneys to prosecute this application and to transact all business in the U.S. Patent and Trademark Office connected therewith: Richard S. Koppel, Reg. No. 26,475; Naomi Mann, Reg. No. 46,431; J.P. O'Shaughnessy, Reg. No. 27,667; and J.J. Deinken, Reg. No. 28,406.

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All statements made herein of my own knowledge are true and all statements made on information and belief are believed to be true. These statements are made with the knowledge that willful false statements and the like are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and may jeopardize the validity of this application or any patent issued thereon.

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